Appendix A Calculations

Ventilation Rate

According to appendix M of the previous report (Blankendaal et al., 2020), the ventilation rate is 6375 m^3/h and the volume of one greenhouse of Upepo is 107.5m^3.
Ventilation rate (m^3/h) = Air Change Rate (/h) x Room Volume (m^3) → Air Change Rate (/h) = 6375/107.5 = 59.3 ach

Drying Rate

Heat Pump Cycle (Temp and Humidity)

First, the following calculation shows the heating and drying cycle in the greenhouse using a heat pump. Given the environment temperature: 23 ℃ and Relative humidity: 65% After heating up, the air temp changes to 40 ℃ then the RH becomes 25%. Assume that the recirculated air absorbed 1.7g/kg of moisture and becomes 35 ℃ and RH 38% (this value is an assumption based on example, however, the situation of UpWind can be very different. Therefore some test should be done to get actual numbers)

Then, the heat exchanger absorbs the heat and lower the temperature to ~21℃. (temperature transfer efficiency ~ 70%) Subsequently, the evaporator cools the air to around 15℃ (the dew point) for dehumidification. Next, the heat exchanger transmits the heat to the dry air and brings the temp to ~ 30℃. The air is soon heated up by the condenser to 40 ℃ (RH 25%). Then the cycle repeats.

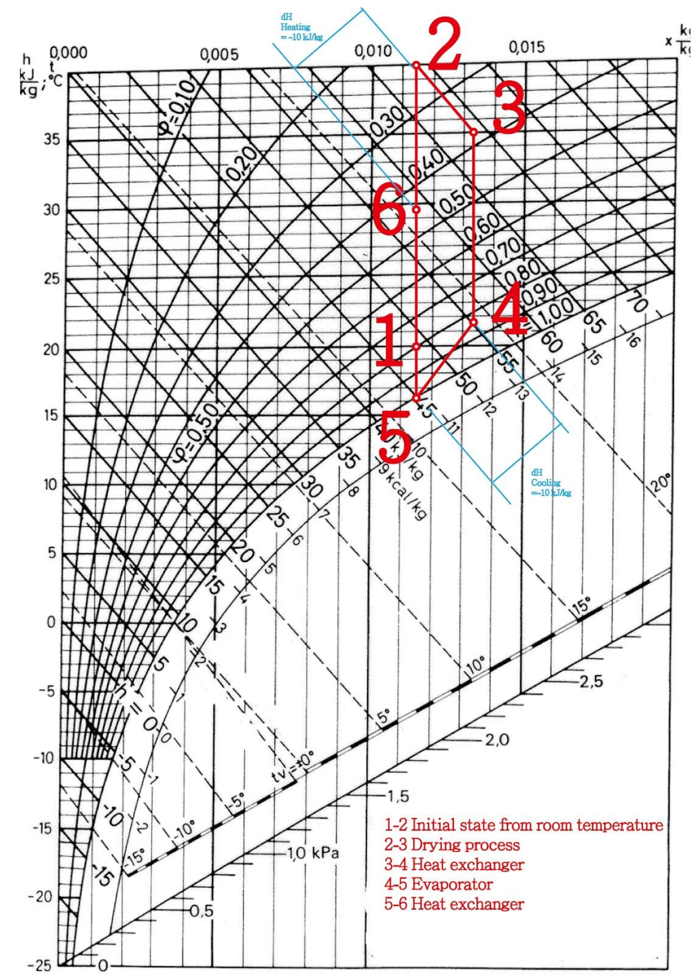

Figure 1. Mollier diagram of the heating and the dehumidification cycle (Adapted from Engineering toolbox, n.d.).

Surface evaporation

Assume the surface of the 20cm sardine is 0.004 m^2 (0.2m*0.1m*2 sides) and assume 40% of the surface area was exposed to the airflow (1.5 m/s). Based on the plot of the research (Bellagha, Amami, Farhat, & Kechaou, 2002, p. 1588), it loses around 17g in 16 hours, which gives the drying rate of ~1.1g/h. Under the same circumstance, water evaporates ~6.85 g/h (Fig 2). This gives an assumption that the drying rate of the sardine is ~16% of that of the water. Based on this number, and the fact that dagaa is smaller than the sardine used in the research, the drying rate of sardine is assumed to be 25% of the rate that water evaporates.

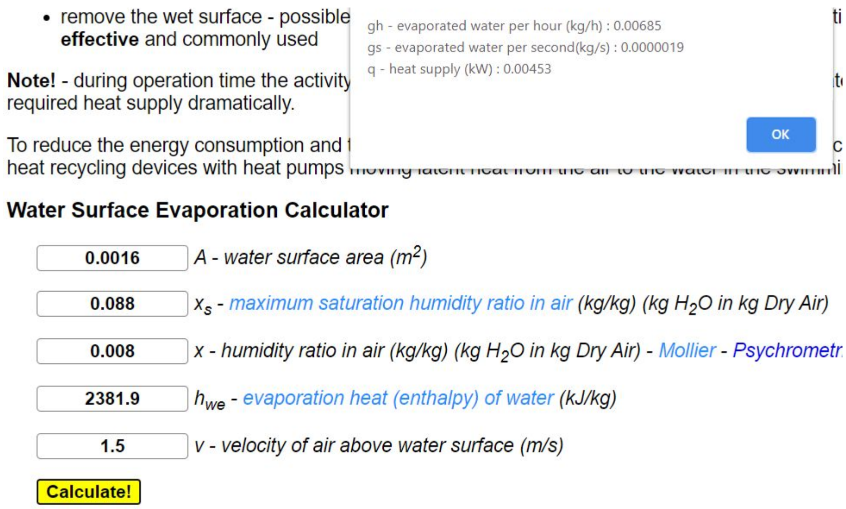

Figure 2. Evaporation rate of water equivalent to a 20cm sardine (retrieved from Engineering toolbox, n.d.)

By the same calculation, the water at 40℃ and RH 25% of 80m^2 evaporate 205kg (Fig 3) of water per hour the evaporation rate of water. According to the assumption, the water evaporates from the fish is 205*0.25 = 51kg.

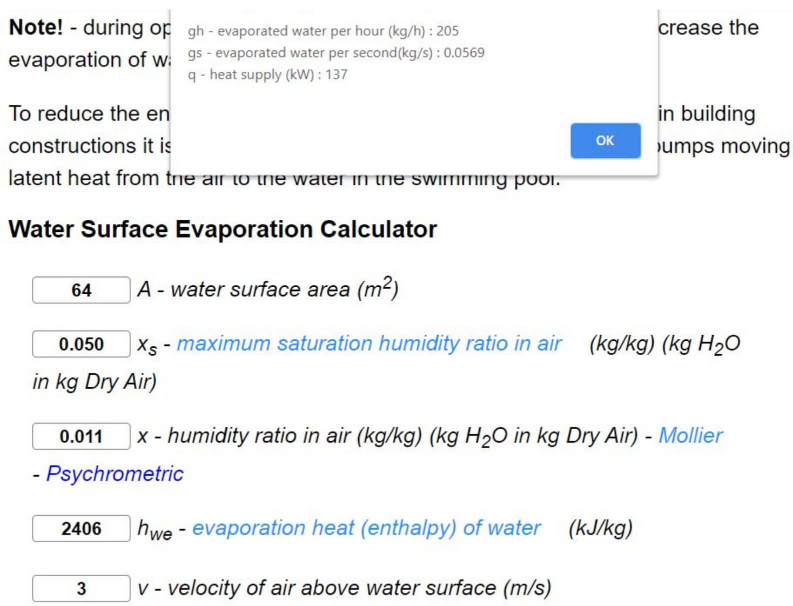

Figure 3. Evaporation rate of water equivalent to 390KG of dagaa (retrieved from Engineering toolbox, n.d.)

**Assume 80% of the drying net is covered by fish, moreover, 40% of the fish surface is in contact with airflow with a velocity of 3 m/s. So the surface area that's exposed to the airflow is 200 m2 x 80% x 40% = 64 m2.*

Moisture to evaporate

Assuming the average moisture content of wet dagaa is 65% and the desired moisture content of dry dagaa is 13%. In this case, 390 kg of dagaa must lose 233kg of moisture content to reach the desired dryness.

Calculating for 1 kg sardine
Initial moisture = 65%
650 g moisture is associated with 350 g dry matter.
Final moisture = 13 %,
130 g moisture are associated with 870 g dry matter,
Therefore
350(dry matter): X (Final moisture) = 870 (Final dry matter) : 130 (Final moisture)
→ Final moisture = (350 x 130)/870 = 52.30 g moisture are associated with 350 g dry matter
1kg of original matter must lose (650 - 52.30) g moisture = 597.7 g = 0.5977 kg moisture.
Therefore, the moisture to evaporate of 390kg dagaa is 390*0.5977 = 233 kg

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Drying time

According to the calculated evaporation rate, it will take 233/51= 4.5 hours* to complete the drying process.

*If the internal temperature reaches 40℃ at all times, both on sunny days and rainy days.

The volume of the drying chamber (excluding the integrated ducting and insulation chamber) is 55m^3, which contains 63 kg of air (air density 1.1455 kg/m^3 at 35℃). Based on the assumption that the recirculated air absorbed 1.7g/kg of moisture (1.7*63 = 107 g of water is taken by the air in on drying chamber), therefore to remove 51kg of water per hour the air change rate should be 300 ach, which means the volume flow rate of the fan should be around 16,500 m^3/h (4.5m^3/s).

Amount of Desiccant

Assume the heat pump can dehumidify 25kg/h, then the desiccant should also dehumidify 25kg/h when using the heat pump. Since silica gel can absorb up to 40% of its own weight. However, assuming silica gel takes 4 hours to be saturated, the average absorption rate per hour is 10% of its own weight. Therefore, it requires 250 kg of desiccant to absorb 25 kg of moisture per hour. However, the number is not realistic, moreover, the calculation involves too many assumptions. Moreover, during rainy days, it is acceptable to have longer drying time as long as it can be dried before the trade of the day. As a result, only 20 kg of desiccant will be used per hour to test the effectiveness first.

References

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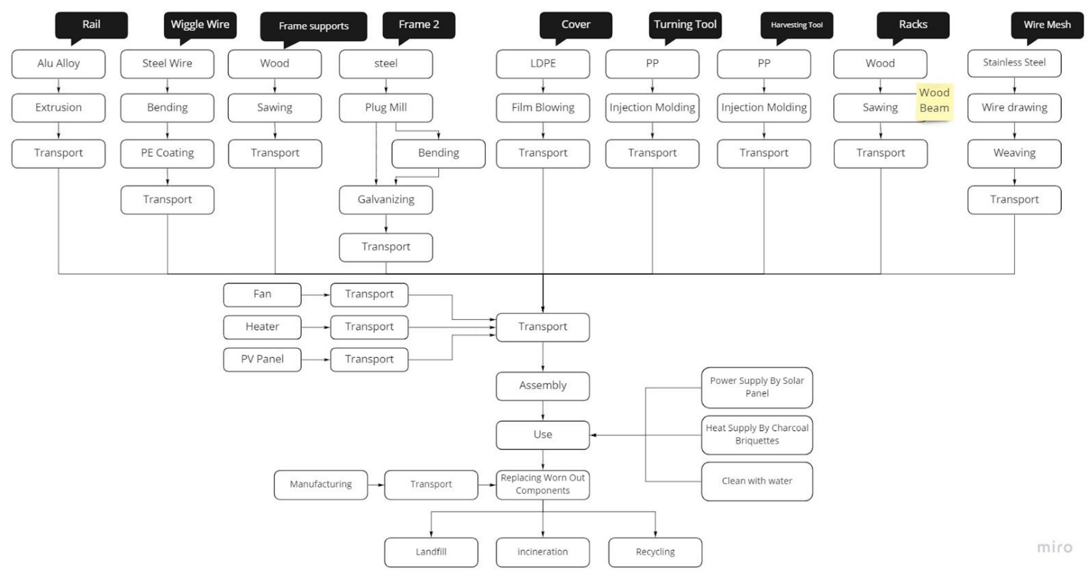
Appendix B-1 LCA Analysis

Objective:

Understanding what impacts are caused by Upepo so as to improve the design when the users dry fish every working day for a year.

Production, distribution, and end of life steps:



Key assumptions for the processes:

Production

The rail is made by extrusion. The material of frame support is Plywood. The wire mesh is stainless steel and the pattern is hexagons. The steel frame tubes are made by plug milling and bending. The tools are injection molded without further post-processing.

Transport

The assembly happens locally, so the components will be sent to SES for storage then sent to the destination of where the product will be used before assembly.

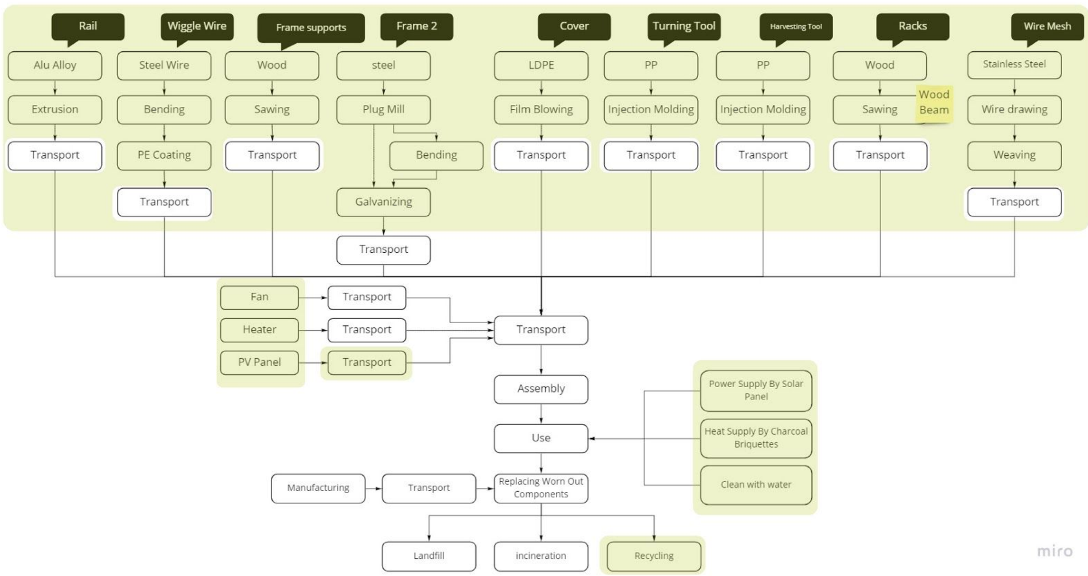
Use scenario

The heater is powered by burning charcoal briquettes. The power of fans is supplied by PV panels. The racks and the greenhouse are cleaned by rinsing with water.

End of life

Consider three end-of-life options: landfill, incineration with energy recovery, and recycling. The recycling system in Tanzania is assumed to be capable of dealing with all kinds of recyclable materials.

Scope and boundaries:



Key assumptions for the system boundaries:

1. Due to the time limitation of the project, the analysis will mainly focus on the greenhouse body. Hence, the production processes of fan, heater, and PV panel are simplified. The production of the fan's frame and the stove is left out. The production and material of the fan's motor and PV cells are directly retrieved from Ecoinvent's database.
2. Due to the lack of information, the transportation of the materials is left out.
3. The post-purchase transport is domestic, it is assumed negligible.
4. The assembly will be done mostly manually with little energy consumption, thus it is left out of the analysis.
5. All waste is incinerated with energy recovery (which would likely be the case for example if separation is ineffective.)
6. The durabilities of the components are not studied, thus, the replacement of worn-out components is not investigated.

Functional Unit:

We will determine the impact (e.g.in CO_2 eq.) of {producing dried dagaa} per {year} for {the design processes 380 kg of dagaa per working day which is 280 days/year}

Material List:

Material	kg	%	Where Used
Steel	168.29	25.21%	Frame: Hoop, corner hoop, top tube, ground tube
Galvanized layer	3.64	0.55%	Galvanized steel of the frame
70#high carbon spring steel	3.01	0.45%	Wiggle Wire for the plastic cover
PE	0.51	0.08%	Wiggle wire coating
Aluminum alloy	5.05	0.76%	Wiggle Wire Rail: Half hoop, base, side, vertical side
Polyethylene	5.78	0.87%	Greenhouse plastic cover+Door
Wood	196.98	29.51%	Frame: Base, Fan support, Door support
PP	3	0.45%	Turning Tool
PP	3	0.45%	Harvesting Tool
Wood beam	152	22.77%	Racks
Galvanized wire	42.8	6.41%	Chicken wire/wire mesh
Fan	36	5.39%	Ventilation
Charcoal stove	30	4.49%	Heating
PV Panel	17.5	2.62%	Supply Fan
Total	667.56	100.00%	

Manufacturing
Aluminum Extrusion
Steel Wire Bending
PE Coating
Wood Sawing
Steel Galvanizing
LDPE Film Blowing
PET Injection Molding
Steel Wire drawing
Process of Fan Manufacturing
Process of Heater Manufacturing
Process of PV Panel Manufacturing

Use	
Lifetime	5 years
Hours / Day Use	4 hours / 280 days
Power Required	370 W
Yearly Power Required	414 kWh / year
Charcoal Briquettes	1,120.00 kg / year
Water	2,400 Liters / year

Disposal	Note
Landfill	
Incineration	
Recycling	

Transport	Distance
To Be Defined	

Key assumptions for Material List

Materials, production, and end of life

1. The detailed dimension can be found in the Datasheet.
2. The weights of most of the materials are estimated by multiplying its volume to its density. Except for the chicken wire, fan, charcoal stove, and PV panel.
3. The weight of the chicken wire is 42.8 kg for 100m^2 (Wire Mesh Manufacture Co., n.d.) with 180g/m^2 galvanized layer. The chicken wire is hexagon-patterned, 13mm of aperture, and 0.65mm of the gauge. The area of the galvanized layer is assumed to be 3.8 m^2 based on the mesh density.
4. The total area of the galvanized layer of the steel tubes is 6 m^2.
5. The thickness of the PE coating layer is 1 mm.
6. The material weight of the tools is estimated based on the assumption that the tool weighs 1 kilogram each and there are three pairs of tools allocated to each greenhouse.
7. The density of the aluminum alloy is assumed to be 2,710 kg/m^3 since the alloy does not vary from the range between 2,640 and 2,810 kg/m^3 (Kissell & Ferry, 2002, pp. 1–3).
8. The material of the cover is assumed to be Low-Density Polyethylene with a density of 940 kg/m^3.
9. The fan is made of a 370w motor and galvanized steel plate.
10. The PV panel is made of sixty PV cells (1.46 m2) (Sunwatt, n.d.)(MATASCI, 2018) and installation on the ground (Gerbinet, Belboom, & Léonard, 2014)
11. The door is a piece of Polyethylene film.
12. Assuming all recyclable materials are recycled properly at the end of its life.
13. The recycling system of Tanzania is assumed to be capable of dealing with all kinds of recyclable materials (The Recycler, n.d.) (Palfreman, 2014)

Transport

1. The materials are assumed to be purchased locally, thus the source of the material should mostly come from Tanzania.

Use

1. The drying process of a day is assumed to be 4 hours with the heating system.
2. The product works 280 days a year.
3. Assuming when the energy release of charcoal equals the energy required of an electrical heater, they would have the same heating effect.
4. The water used by cleaning the rack and the greenhouse is estimated by calculating the volume of a hose of 12L/min flow rate over a 5-minute duration once in a working week.

Interpretation:

The goal of this analysis is to determine the sustainability impact, namely Carbon Footprint, Cumulative energy demand (CED), ReCiPe Human Health, ReCiPe Ecotoxicity, and ReCiPe Resources of the product's material, production, transport, use, and end of life over a period of one year (280 working days) in order to improve the design. The production of the design is set at a capability of processing 380 kg of dagaa per working day.

After all the data has been retrieved from Idemat and Ecoinvent, the impacts were analyzed (see Datasheet) and compared by each phase of the product (Figure 1), four major parts of the product (Figure 2), and each component of the greenhouse (Figure 3).

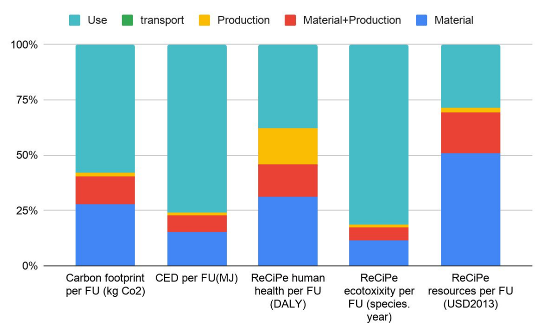


Figure 1. Relative Impact of the Product's Life Cycle

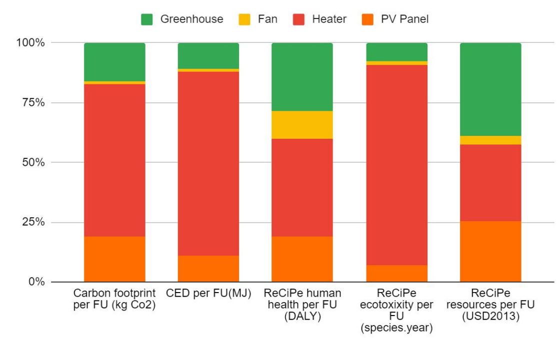


Figure 2. Relative Impact of the Four Major Parts of the Product

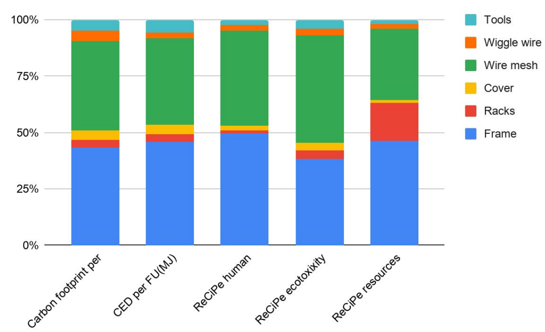
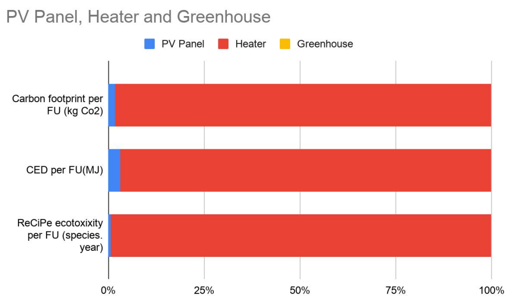


Figure 3. Relative Impact of the Components of the Greenhouse

According to Figure 1, the impact of the use phase on Carbon Footprint, Cumulative energy demand (CED), and ReCiPe Ecotoxicity are relatively higher than other phases. In addition, the impact of the material phase on ReCiPe Resources is relatively higher than other phases. Furthermore, Figure 4 shows that the heater is the main impact cause of the use phase, and Figure 5 shows that the greenhouse is the main impact cause of the material phase



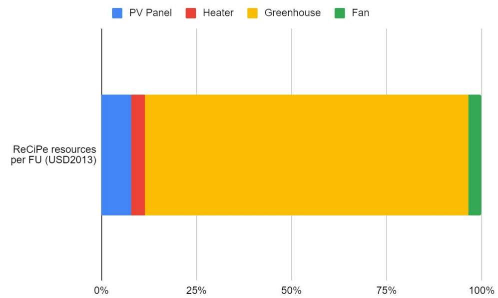


Figure 4. Relative Impact of PV Panel and Heater of Use Phase of Material Phase

Figure 5. Relative Impact of Four Major Parts of the Product

According to Figure 2, the impact of the heater on Carbon Footprint, Cumulative energy demand (CED), and ReCiPe Ecotoxicity are relatively higher than other parts. Furthermore, Figure 6 shows that the use phase of the heater is the main impact cause of the heater.

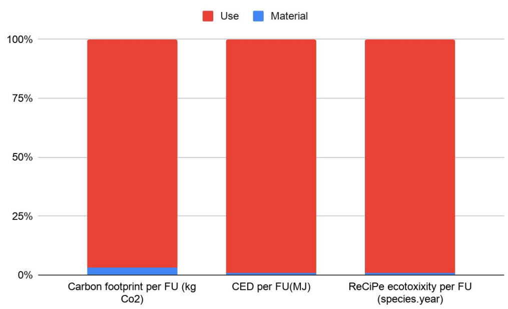
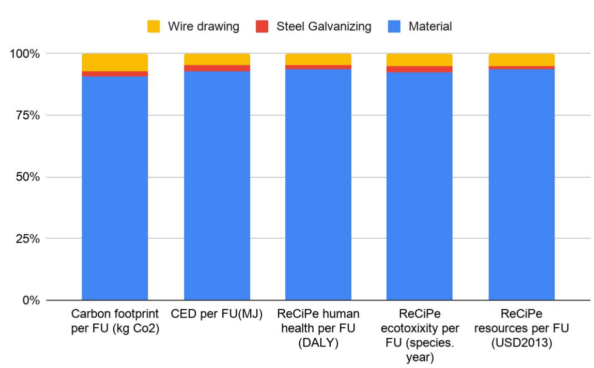


Figure 6. Relative Impact of the Use and Material Phase of the Heater

According to Figure 3, the impacts of the wire mesh and the frame on every index are relatively higher than other components. Furthermore, Figure 7 shows that the material (stainless steel) is the main impact cause of the wire mesh, and Figure 8 shows that, overall, steel tube is the main impact cause of the frame, while steel galvanizing accounts for a high percentage of ReCiPe Human health impact and yellow pine accounts for a high percentage of ReCiPe Resources impact.



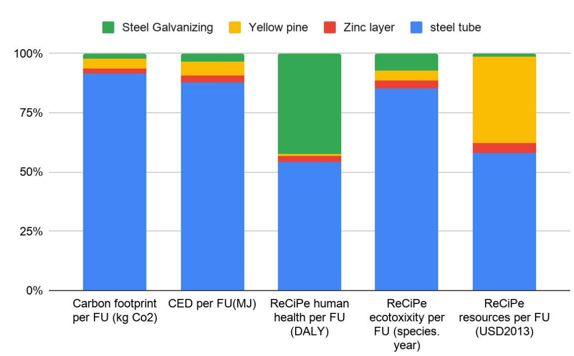


Figure 7. Relative Impact of the Each Phase of the Wire Mesh Mesh

Figure 8. Relative Impact of the Each Phase of the Wire

Although the relative impact does not represent the actual impact, the figures still provide some useful information at this stage. The following elements are highly influencing the impact of the product: the fuel of the heater, the material of the frame, and the material of the wire mesh. It may seem to be obvious right now, but the database established can be used for the material selection of future design. Moreover, by the time future design is generated, the total impact of the designs can be compared with the assumptions and scope carefully dealt.

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Appendix B-2 LCA Datasheet

Category	Description - Material	Unit	Amount per	No. of items	Amount	Source	Reference	Description	Carbon footprint	CED per	ReCiPe human	ReCiPe ecotoxixity	ReCiPe resources	Carbon footprint	CED per	ReCiPe human	ReCiPe ecotoxixity	ReCiPe
Material	Frame - steel tube	kg	282.32	1	282.32	Idemat 2020	A.100.03.104	Steel beams, pipes, sheet (from market mix 44% recycle	1.79	27.4	0.000	0.000	0.079	505.353	7,735.568	0.001	0.000	22.314
Material	Frame - Zinc layer	kg	6.7	1	6.7	Idemat 2020	A.100.14.152	Zinc trade mix (77% prim 23% sec	1.75	41.97	0.000	0.000	0.246	11.725	281.199	0.000	0.000	1.645
Material	Frame - Pine	kg	196.98	1	196.98	Idemat 2020	A.160.04.136	Yellow pine FSC/PEFC 540 (kg/m3	0.07	1.59	0.000	0.000	0.042	13.789	313.198	0.000	0.000	8.369
Material	Racks - Wood beam	kg	152	1	152	Idemat 2020	A.160.04.136	Yellow pine FSC/PEFC 540 (kg/m3	0.07	1.59	0.000	0.000	0.042	10.640	241.680	0.000	0.000	6.458
Material	Wire mesh - Stainless steel wire	kg	42.8	1	42.8	Idemat 2020	A.100.05.117	X6CrNi18 (~304)	4.24	79.9	0.000	0.000	0.303	181.472	3,419.720	0.001	0.000	12.987
Material	Wiggle wire - steel	kg	0.96	1	0.96	Idemat 2020	A.100.03.102	Steel (21% sec = market mix average	1.78	20.29	0.000	0.000	0.073	1.709	19.478	0.000	0.000	0.070
Material	Wiggle wire - PE	kg	0.51	1	0.51	Idemat 2020	A.130.04.112	PE (LDPE, Low density Polyethylene	2.27	80.87	0.000	0.000	0.633	1.158	41.244	0.000	0.000	0.323
Material	Wiggle wire rail - Aluminum alloy	kg	5.05	1	5.05	Ecoinvent	A.100.01.202	Aluminium alloy, AlMg3 {GLO}| market for | Cut-off, S	7.15	90.16	0.000	0.000	0.310	36.108	455.308	0.000	0.000	1.566
Material	Cover - Polyethylene (LDPE)	kg	5.78	1	5.78	Idemat 2020	A.130.04.112	PE (LDPE, Low density Polyethylene	2.27	80.87	0.000	0.000	0.633	13.121	467.429	0.000	0.000	3.661
Material	Turning Tool - PP	kg	3	1	3	Idemat 2020	A.130.04.121	PP (Polypropylene	2.12	76.46	0.000	0.000	0.654	6.360	229.380	0.000	0.000	1.962
Material	Harvesting Tool - PP	kg	3	1	3	Idemat 2020	A.130.04.121	PP (Polypropylene	2.12	76.46	0.000	0.000	0.654	6.360	229.380	0.000	0.000	1.962
Production	Racks - Wood Sawing	s	460	1	460	Idemat 2020	D.150.01.102	Power sawing (petrol	0.0019	0.036	0.000	0.000	0.000	0.874	16.560	0.000	0.000	0.161
Production	Frame - Steel Galvanizing	m2	11	1	11	Idemat 2020	D.070.01.103	Electroplating Zinc, incl. outside use, per 10 year	1.97	49.889	0.000	0.000	0.088	21.670	548.779	0.002	0.000	0.972
Production	Wire mesh - Steel Galvanizing	m2	3.8	1	3.8	Idemat 2020	D.070.01.104	Electroplating Zinc, inside use or painted (5 micron	0.99	25.011	0.000	0.000	0.044	3.762	95.042	0.000	0.000	0.168
Production	Wire mesh - Wire drawing	kg	43.76	1	43.76	Ecoinvent	D.050.01.269	Wire drawing, steel {GLO}| market for | Cut-off, S	0.32	3.579	0.000	0.000	0.016	14.003	156.617	0.000	0.000	0.687
Production	Turning tool - Injection Molding	kg	3	1	3	Idemat 2020	D.120.01.305	Injection moulding	1.19	30.368	0.000	0.000	0.046	3.570	91.104	0.000	0.000	0.137
Production	Harvesting tool - Injection Molding	kg	3	1	3	Idemat 2020	D.120.01.305	Injection moulding	1.19	30.368	0.000	0.000	0.046	3.570	91.104	0.000	0.000	0.137
Production	Cover - LDPE Film Blowing	kg	5.78	1	5.78	Idemat 2020	D.120.01.302	Blow moulding UPVC film	0.5	8.191	0.000	0.000	0.022	2.890	47.344	0.000	0.000	0.128
Production	Wiggle wire rail - Aluminum Extrusion	kg	5.05	1	5.05	Ecoinvent	D.050.01.217	Impact extrusion of aluminium, 1 stroke {GLO}| market for | Cut-off,	0.96	13.97	0.000	0.000	0.051	4.848	70.549	0.000	0.000	0.260
Material	Heater - Charcoal Briquettes	kg	560	1	560	Ecoinvent	A.070.06.201	Charcoal {GLO}| market for | Cut-off, S	1.43	53.94	0.000	0.000	0.029	800.800	30,206.400	0.001	0.000	16.010
Use	Heater - Charcoal Briquettes	MJ	16,505	1	16505	Ecoinvent	B.050.03.203	Heat, central or small-scale, other than natural gas {RoW}| heat productio	0.154	1.445	0.000	0.000	0.004	2,541.770	23,849.725	0.006	0.000	74.245
Use	Fan - Solar power	MJ	1491.84	1	1491.84	Idemat 2020	B.030.01.307	PV panel on roof 3KWp (ribbon-Si, Switserland	0.019	1.304	0.000	0.000	0.001	28.345	1,945.359	0.000	0.000	1.680
Use	Water	kg	2400	1	2400	Ecoinvent	A.150.01.206	Tap water {RoW}| market for | Cut-off, S	0.0007	0.0098	0.000	0.000	0.000	1.680	23.520	0.000	0.000	0.089
													Sub total	4,215.575	70,575.687	0.011	0.000	155.993
End of life	Frame - Galvanized steel recycling	kg	282.32	1	282.32	Idemat 2020	F.110.01.108	Steel, recycling credit closed loop (56% virgin part in market mi	-0.88	-7.273	0.000	0.000	-0.024	-248.442	-2,053.313	-0.001	0.000	-6.839
End of life	Wire Mesh - stainless steel recycling	kg	42.8	1	42.8	Idemat 2020	F.110.01.108	Steel, recycling credit closed loop (56% virgin part in market mi	-0.88	-7.273	0.000	0.000	-0.024	-37.664	-311.284	0.000	0.000	-1.037
End of life	Wiggle wire - PE coated steel recycling	kg	0.96	1	0.96	Idemat 2020	F.110.01.108	Steel, recycling credit closed loop (56% virgin part in market mi	-0.88	-7.273	0.000	0.000	-0.024	-0.845	-6.982	0.000	0.000	-0.023
End of life	Wiggle wire rail - Aluminum alloy recyli	kg	5.05	1	5.05	Idemat 2020	F.110.01.101	Aluminium, recycling credit closed loop (66% virgin part market mi	-5.33	-81.798	0.000	0.000	-0.311	-26.917	-413.080	0.000	0.000	-1.572
End of life	Turning Tool - PP Recycling	kg	3	1	3	Idemat 2020	F.120.01.117	PP (Polypropylene), recycling cred	0.08	-21.438	0.000	0.000	-0.561	0.240	-64.314	0.000	0.000	-1.684
End of life	Harvesting Tool - PP Recycling	kg	3	1	3	Idemat 2020	F.120.01.117	PP (Polypropylene), recycling cred	0.08	-21.438	0.000	0.000	-0.561	0.240	-64.314	0.000	0.000	-1.684
End of life	Cover - Polyethylene (LDPE) recycling	kg	5.78	1	5.78	Idemat 2020	F.120.01.110	PE (Polyethylene), recycling cred	0.09	-24.088	0.000	0.000	-0.558	0.520	-139.229	0.000	0.000	-3.223
													Sub total	-312.867	-3,052.516	-0.001	0.000	-16.062
PV Panel																		
Material+Pr	PV Cell	m2	1.00	1.46	1.46	Ecoinvent	A.050.05.211	Photovoltaic cell, single-Si wafer {GLO}| market for | Cut-off,	240.380	3,866.640	0.001	0.000	13.521	350.955	5,645.294	0.001	0.000	19.740
Installation																		
Material	aluminium, production mix, wrought all	kg	5.81	1	5.81	Ecoinvent	A.100.01.207	Aluminium, wrought alloy {GLO}| market for | Cut-off, S	12.140	137.650	0.000	0.000	0.457	70.543	799.857	0.000	0.000	2.656
Material	corrugated board, mixed fibre, single w	kg	0.13	1	0.13	Ecoinvent	A.120.03.202	Corrugated board box {RER}| market for corrugated board box | Cut-off,	0.930	23.400	0.000	0.000	0.092	0.117	2.952	0.000	0.000	0.012
Material	polyethylene, HDPE, granulate, at plant	kg	0.00	1	0.00	Ecoinvent	A.130.04.230	Polyethylene, high density, granulate {GLO}| market for | Cut-off,	2.090	78.510	0.000	0.000	0.649	0.003	0.104	0.000	0.000	0.001
Material	polystyrene, high impact, HIPS, at plan	kg	0.01	1	0.01	Ecoinvent	A.130.04.244	Polystyrene, high impact {GLO}| market for | Cut-off, S	3.740	89.510	0.000	0.000	0.756	0.025	0.595	0.000	0.000	0.005
Material	chromium steel 18/8, at plant	kg	0.36	1	0.36	Ecoinvent	A.100.03.210	Steel, chromium steel 18/8 {GLO}| market for | Cut-off, S	4.510	66.120	0.000	0.000	0.348	1.626	23.844	0.000	0.000	0.125
Material	reinforcing steel, at plant	kg	10.53	1	10.53	Ecoinvent	A.100.03.208	Reinforcing steel {GLO}| market for | Cut-off, S	2.110	26.270	0.000	0.000	0.124	22.211	276.534	0.000	0.000	1.306
Material	concrete, normal, at plant	m3	0.00	1	0.00	Ecoinvent	A.040.05.214	Concrete, normal {RoW}| market for | Cut-off, S	228.890	1,711.340	0.000	0.000	12.082	0.179	1.342	0.000	0.000	0.009
Production	section bar extrusion, aluminium	kg	5.81	1	5.81	Ecoinvent	D.050.01.262	Section bar extrusion, aluminium {GLO}| market for | Cut-off,	0.950	18.193	0.000	0.000	0.054	5.520	105.716	0.000	0.000	0.314
Production	section bar rolling, steel	kg	8.98	1	8.98	Ecoinvent	D.050.01.263	Section bar rolling, steel {GLO}| market for | Cut-off, S	0.160	1.800	0.000	0.000	0.008	1.437	16.162	0.000	0.000	0.068
Production	wire drawing, steel	kg	1.55	1	1.55	Ecoinvent	D.050.01.269	Wire drawing, steel {GLO}| market for | Cut-off, S	0.320	3.579	0.000	0.000	0.016	0.495	5.539	0.000	0.000	0.024
Production	zinc coating, pieces	m2	0.23	1	0.23	Ecoinvent	D.070.01.214	Zinc coat, pieces {GLO}| market for | Cut-off, S	7.470	95.867	0.000	0.000	0.498	1.701	21.835	0.000	0.000	0.113
Production	zinc coating, coils	m2	0.16	1	0.16	Ecoinvent	D.070.01.213	Zinc coat, coils {GLO}| market for | Cut-off, S	4.870	70.940	0.000	0.000	0.405	0.775	11.289	0.000	0.000	0.064
transport	lorry >16t, fleet average	tkm	0.32	1	0.32	Ecoinvent	C.060.01.220	Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freigh	0.160	2.714	0.000	0.000	0.025	0.051	0.860	0.000	0.000	0.008
transport	freight, rail	tkm	7.50	1	7.50	Ecoinvent	C.050.01.211	Transport, freight train {Europe without Switzerland}| diesel | Cut-off,	0.060	0.846	0.000	0.000	0.007	0.450	6.349	0.000	0.000	0.053
transport	van <3.5t	~~tkm~~	1660.00	1	1660.00	Idemat2020	C.060.02.106	Delivery Van 5m3 <3,5	0.000	0.004	0.000	0.000	0.000	0.432	6.142	0.000	0.000	0.059
End of life	disposal, packaging cardboard, 19.6%	kg	0.13	1	0.13	Idemat2020	F.080.01.108	Paper, Cardboard, Leather, Cotton (12%MC) waste incineration with elec	-0.690	-11.274	0.000	0.000	-0.085	-0.087	-1.422	0.000	0.000	-0.011
													Sub total	456.434	6,922.991	0.001	0.000	24.548
Stove																		
Material	Steel	kg	30	1	30.00	Idemat 2020	A.100.03.102	Steel (21% sec = market mix average	1.780	20.290	0.000	0.000	0.073	53.400	608.700	0.000	0.000	2.188
													Sub total	53.400	608.700	0.000	0.000	2.188
End of life	Recycling steel	kg	30	1	30.00	Idemat2020	F.110.01.108	Steel, recycling credit closed loop (56% virgin part in market mi	-0.880	-7.273	0.000	0.000	-0.024	-26.400	-218.190	0.000	0.000	-0.727
													Sub total	-26.400	-218.190	0.000	0.000	-0.727
Fan																		
Material+Pr	370W Motor	kg	6.5	1	6.50	Idemat 2020	A.050.04.303	Electric motor, less than 500 W, estimate	0.160	53.140	0.000	0.000	0.325	1.040	345.410	0.000	0.000	2.111
Material	Steel plate	kg	28.34	1	28.34	Idemat 2020	A.100.03.102	Steel (21% sec = market mix average	1.780	20.290	0.000	0.000	0.073	50.445	575.019	0.000	0.000	2.067
Production	Steel Galvanizing	m2	3.52	1	3.52	Idemat 2020	D.070.01.103	Electroplating Zinc, incl. outside use, per 10 year	1.97	49.889	0.000	0.000	0.088	6.934	175.609	0.001	0.000	0.311
													Sub total	58.420	1,096.038	0.001	0.000	4.489
End of life	Recycling steel	kg	28.34	1	28.34	Idemat2020	F.110.01.108	Steel, recycling credit closed loop (56% virgin part in market mi	-0.880	-7.273	0.000	0.000	-0.024	-24.939	-206.117	0.000	0.000	-0.687
													Sub total	-24.939	-206.117	0.000	0.000	-0.687
													Total(w/o Recycling	4,783.829	79,203.415	0.013	0.000	187.218
													Total(w/ Recycling	4,419.623	75,726.592	0.012	0.000	169.743
													Recycling	-364.206	-3,476.823	-0.001	0.000	-17.475

Appendix C Comparison of Solar Dryers

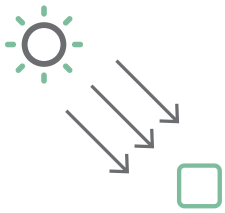
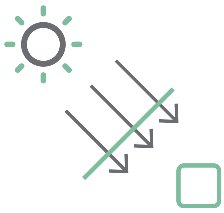
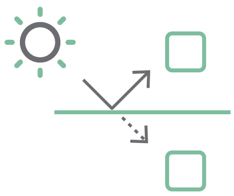
Mode	Description
Open Sun Dryer 	Dries foodstuffs with direct sunlight in the open air (e.g. Current sand drying method). *Pros* Low cost *Cons* Heat losses and yield losses due to various reasons such as animal, micro-organisms, natural factors, contamination, discoloration by UV, dependent on sunlight
Direct Solar Dryer 	Dries foodstuffs within an enclosed box with transparent cover, which allows sun radiation entry and air vents, which allow air exchanges (e.g. Cabinet dryer). *Pros* Safe from yield loss due to animal, rain, and contamination *Cons* Discoloration, condensation of the moisture on the cover, dependent on sunlight, limited space
Indirect Solar Dryer 	Dries foodstuffs using solar energy without exposing the objects directly to solar radiation.(e.g. Reverse absorber cabinet dryer, solar-energy collector, greenhouse dryer). *Pros* Minimize discoloration and cracking on the surface of the crop. *Cons* Dependent on sunlight

Table 1. Three Modes of Solar Drying (Adapted from Sharma et al., 2009, p. 1189)

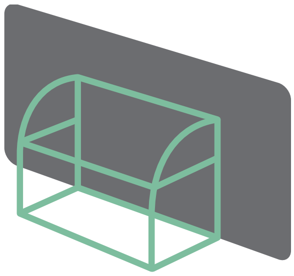
Reference

Sharma, A., Chen, C. R., & Vu Lan, N. (2009). Solar-energy drying systems: A review. Renewable and Sustainable Energy Reviews, 13(6–7), 1189. https://doi.org/10.1016/j.rser.2008.08.015

Appendix D Greenhouse Information

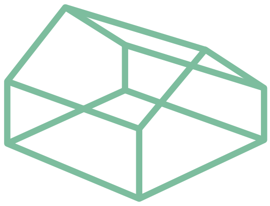
There are different types of greenhouse, they differ in shapes, constructions, and covering materials (adapted from DMGH, 2013) . Each of them has different stability, suitable circumstances, lifespan, drawbacks, and cost.

Shapes



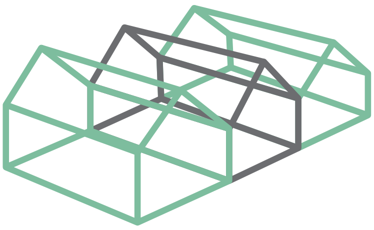
Lean-to

- Least expensive
- Attached to house, minimized roof supports
- Limited space, light, ventilation and temperature control



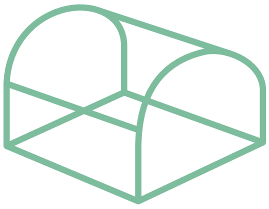
Even-span

- Small size
- Common dimension ranges: 2.4-6m / 3.6-12m / 2.5-3.6m (W/L/H)
- Constructed on level ground



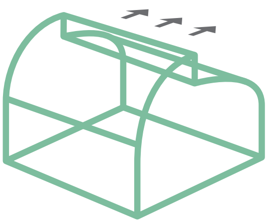
Ridge and furrow

- Two or more A-frame greenhouses connected
- The sidewall is eliminated between the greenhouses
- Lowers the cost of automation



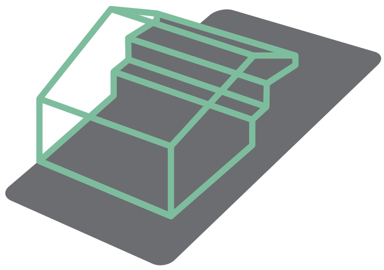
Quonset

- Less expensive
- Useful when a small isolated cultural area is required
- Connected either in free, standing style or arranged in an interlocking ridge and furrow



Sawtooth

- Similar to ridge and furrow type
- Provision for natural ventilation



Uneven-span

- Constructed on hilly terrain
- Roofs are of unequal width

Constructions

Wooden framed

- Used when the span is less than 6 m
- Pinewood: inexpensive and possesses the required strength
- Timber: good strength, durability, and machinability

Pipe framed

- Used when the span is around 12m

Truss framed

- Used when the span is greater than or equal to 15m
- Columns are used for long-span houses of 21.3 m or more
- Most of the glasshouses are of truss frame type

Covering Materials

Glass

- Greater interior light intensity
- Suitable for lean-to, even-span, ridge and furrow types
- High cost

Plastic film

- Cheap material: polyethylene, polyester, and polyvinyl chloride
- Cost of heating is less when compared to glass greenhouses
- Last for four years only (best quality ultraviolet (UV) stabilized film)
- Suitable for Quonset and gutter-connected types

Rigid panel

- Polyvinyl chloride, fiberglass-reinforced, and polycarbonate
- Resistant to breakage
- Light intensity is uniform throughout the greenhouse
- Long-life even up to 20 years
- Tend to collect dust and harbor algae
- Significant danger of fire hazard.

List of Greenhouse Parameters

Parameter	Influence	Description/Suggestion
Size of openings	Heat losses and airflow rate[a]	Ridge and side vents should be about one fourth the floor area. The roof vents should open above the horizontal position to provide about a 60-degree angle to the roof[a]
Surface area	Heat losses and capacity[b]	In general, the larger the surface area, the greater the heat loss[a]
Height	Heat losses and capacity [b]	Heights of most greenhouses are between 2.5 and 3.6 meters[d]
Layer of stacks	Airflow rates, drying rates[b] and capacity	The layer number negatively correlated to the drying performance[b]
Temperature difference	Heat losses and airflow[c]	The temperature difference between the greenhouse and the ambient air. Chimney effect is an example of application[c]
Shade	Sunlight Exposure[c]	No building or trees on the east side[c]
Wind	Structure damage[c] and ventilation[d]	For less wind: protected areas are better sites than exposed hilltops. To utilize wind: sawtooth type greenhouses
Drainage	Sanitation[c]	Install a slope or shallow trench along the edges[c]
Covering Materials	Heat losses and UV stability[c]	Glass, plastic film, rigid panel[d]
Orientation	Sunlight exposure	For latitudes lower than 40: north-south. For higher latitudes: east-west[c]
Size	Heat collection[c]	A ratio of 1:2 of floor area: ideal for passive greenhouse dryers[c]
Ventilation	Indoor temperature, humidity, evaporation rate, and airflow	Passive: turbo exhaust fan and attic ventilator Active fan: series layout, parallel layout, horizontal and vertical airflow[e], fan for greenhouses[f], exhaust fans in the end wall, and pressure fans in end walls (suitable for length less than 30meter)[a]
Supplementary Heat	Indoor temperature, evaporation rate	External heating source: Top-lit-up-draft[c g] Heat storage: PCMs[c] Mix [c]

Table 1. Parameters that influence the performance of a Greenhouse

[a]Worley (2014). [b]Ndirangu, Kanali, Mutwiwa, Kituu, & Ronoh (2018, pp. 27-35). [c]Akinjiola & Balachandran (2012, pp. 40-49). [d]DMGH (2013). [e]Sparks (2018). [f]Buffington, Bucklin, Henley, & McConnell (1992). [g]Appropedia (2011).

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Akinjiola, O. P., & Balachandran, U. (Balu). (2012). Mass-Heater Supplemented Greenhouse Dryer for Post-Harvest Preservation in Developing Countries. Journal of Sustainable Development, 5(10), 42. https://doi.org/10.5539/jsd.v5n10p40

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Buffington, D. E., Bucklin, R. A, Henley, R. W, & McConnell, D. B. (1992). Fans For Greenhouses. Retrieved from https://edis.ifas.ufl.edu/ae020#FIGURE%209

DMGH. (2013, December 16). DMGH: Lesson 1 History and Types of Greenhouse. Retrieved May 8, 2020, from http://ecoursesonline.iasri.res.in/mod/page/view.php?id=1604

Ndirangu, S. N., Kanali, C. L., Mutwiwa, U. N., Kituu, G. M., & Ronoh, E. K. (2018). Analysis of Designs and Performance of Existing Greenhouse Solar Dryers in Kenya. Journal of Postharvest Technology, 6(1), 27–35. Retrieved from http://jpht.info/index.php/jpht/article/view/20356/9912

Sparks, B. (2018, August 8). Four Keys to Optimal Air Flow in the Greenhouse. Retrieved May 9, 2020, from https://www.greenhousegrower.com/technology/heating-cooling-ventilation/four-keys-to-optimal-air-flow-in-the-greenhouse/

Worley, J. (2014). GREENHOUSES Heating, Cooling and Ventilation. Athens, GA: UGA Extension.

Appendix E List of Other Dryers

Category	Dryers
Direct Dryers (convection)	Cross circulation *Examples* Tray dryers, kiln dryers, tunnel dryers, Through-circulation *Examples* Rotary dryers, drum dryers, oven dryers Slow-moving gas stream *Examples* Superheated steam dryers, heat-pump-assisted dryers High-velocity hot gas stream *Examples* Spray dryers, flash dryers
Indirect or contact (conduction)	*Examples* Fluidized-bed dryers, Continuous fluid-bed dryers
Other Technologies	Ultrasonic *Examples* Sonic dryers Radiant *Examples* Dielectric or microwave dryers, Infrared (IR) dryers Pressure *Examples* Vacuum dryers, freeze dryers, modified atmosphere drying

Table 1. Non-solar Dryers (adapted from Parikh, 2014., Rahman, 2006., Tucker, 2016)

References

Parikh, D. M. (2014, April 1). Solids Drying: Basics and Applications. Retrieved May 8, 2020, from https://www.chemengonline.com/solids-drying-basics-and-applications/?printmode=1

Rahman, M. S. (2006). Drying of Fish and Seafood. Handbook of Industrial Drying, Third Edition, 6. https://doi.org/10.1201/9781420017618.ch22

Tucker, G. S. (2016). Food Preservation and Biodeterioration (2nd ed.). Hoboken, NJ, United States: Wiley.

Appendix F-1 List of Ventilation Parameters

Parameter | Description

Sizing of Openings

Influence the ventilation rate. Buildings require permanently open vents, to provide background ventilation, and controllable openings to meet transient demand.

Building Air-tightness

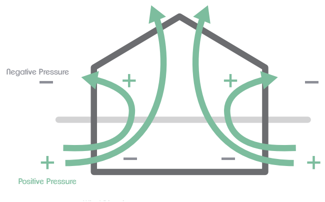
Except for the opening, the building should be airtight to achieve the intended airflow.

Positioning of Openings

Air enters through the lower openings and escapes through the higher openings when the inside air temperature is greater than outside.

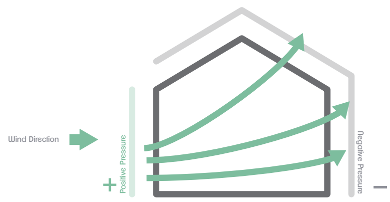
Stack Pressure

Based on air temperature differences, which cause airflow in the building.



Wind Pressure

Wind striking induces a positive pressure on the windward face and negative pressures on opposing faces and some side faces.



Stack Pressure & Wind Pressure

Different wind velocities cause different airflow patterns

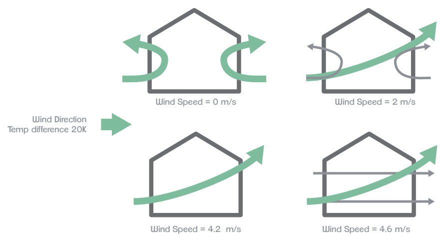


Table 1. Natural Ventilation Parameters (Adapted from Liddament & Air Infiltration and Ventilation Centre, 1996, pp. 87–94)

While designing for natural ventilation, the following conditions should be kept in mind. Firstly, natural ventilation is suitable for mild (annual CDD<2000) or moderate climates (annual CDD between 2000 and 3000) (Liddament & Air Infiltration and Ventilation Centre, 1996, p. 87). Secondly, inadequate control over ventilation rate could lead to indoor heat loss but can be reduced by incorporating exhaust air heat recovery techniques, where mechanical ventilation might be required (Liddament & Air Infiltration and Ventilation Centre, 1996, p. 99).

* CDD(cooling degree day) = daily avg. temperature (°F) minus 65 °F

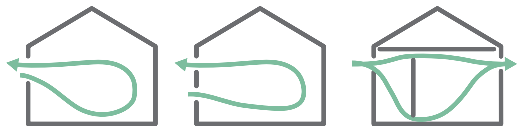
References

Liddament, M. W., & Air Infiltration and Ventilation Centre. (1996). A Guide to Energy Efficient Ventilation. Coventry, UK: Air Infiltration and Ventilation Centre.

Appendix F-2 Descriptions of Ventilation Strategies

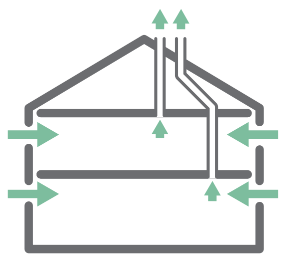
Crossflow Ventilation

Create an unimpeded path for air to flow through the intended area. The limitation of this ventilation is that the depth should ideally be 2 to 2.5 times but maximum be 5 times the ceiling height



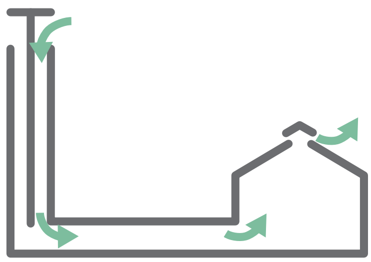
Single-sided Ventilation

It is unreliable and not recommended as part of a controlled natural ventilation strategy. For this situation, more than one opening may be placed on a single side or a single opening is large enough for air to flow simultaneously through it in both directions



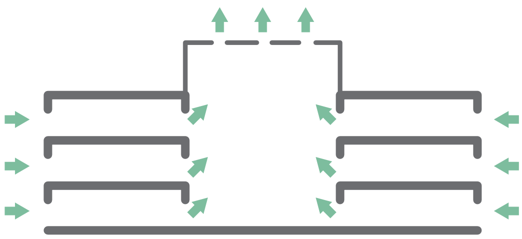
Passive Stack Ventilation

Vertical ducts are deployed at each space for ventilation. It is normally used to promote the extraction of air from 'wet' rooms.



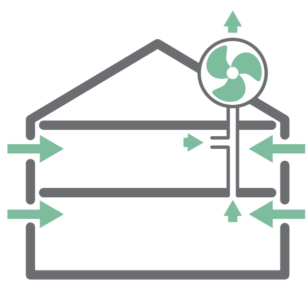
Wind towers

Prevailing wind provides a reliable driving force to form a 'wind tower', which results in wind-driven airflow being ducted into the building.



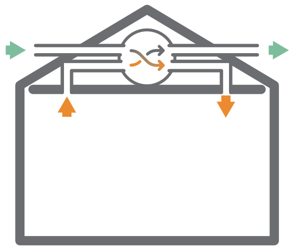
Atria ventilation

An atrium is a glass-covered courtyard which gathers heat from the sun to drive airflow towards it.



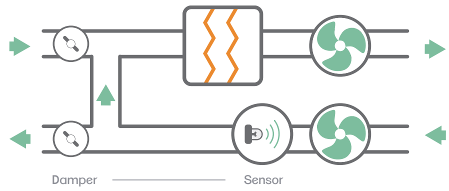
Mechanical Extract Ventilation

The fan exhausts stale air which drives the fresh air into the space through intended openings



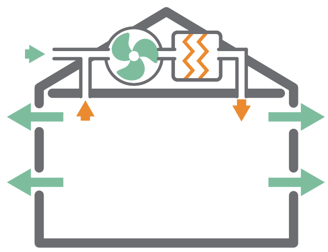
Mechanical Balanced Ventilation

It combines extract and supply systems. It allows heat recovery and prevents pollution from outside.



Demand Controlled Ventilation

This strategy efficiently controls the air change and filtration with sensors.



Mechanical Supply Ventilation

The air is blown into the room, then the indoor air is blown out through the openings. This strategy is often combined with a filtration or conditioning unit, which makes the air quality controlled but heat recovery is not possible.

Table 1. Ventilation Strategies (Adapted from Liddament & Air Infiltration and Ventilation Centre, 1996, pp. 87–114)

References

Liddament, M. W., & Air Infiltration and Ventilation Centre. (1996). A Guide to Energy Efficient Ventilation. Coventry, UK: Air Infiltration and Ventilation Centre.

Appendix F-3 List of Ventilators

Ventilator	Application
Controllable openings	Openable windows and louvers
Uncontrolled	Trickle ventilators (Winter), air vents, attic ventilation, and turbo vents
Automatic inlets	Temperature-sensitive vents, humidity-sensitive vents, and pressure-sensitive vents
Passive stacks	Vertical ducts plus Cowels ventilator, chimney effect
Air vents for combustion appliances	Balanced flues and externally supplied and exhausted air
Propeller fans	For low capacity
Centrifugal and axial fans	For high capacity and lengthy duct runs

Table 1. An Overview of Ventilators (Adapted from Liddament & Air Infiltration and Ventilation Centre, 1996, pp. 87–114)

References

Liddament, M. W., & Air Infiltration and Ventilation Centre. (1996). A Guide to Energy Efficient Ventilation. Coventry, UK: Air Infiltration and Ventilation Centre.

Appendix F-4 List of Dehumidification Methods

Condensation	*Heat pump*	*Dehumidifier*
	Capillarity	
Air exchange	*Ventilation*	*Open window*
		Exhaust/Ventilation Fans
Absorption	*Water-Absorbing Material*	*Charcoal Briquettes, Sisal, Rock salt*
	Plants	*Cactus*
Source control	*Plants*	*Remove plants that emit moisture*
	Vapor	*Avoid the use of hot water*
	Water	*Avoid water ponding*

Appendix G List of Protection Methods for UV/ Animal/Rain

UV damage
- UV absorbing materials such as Polyester (Rai, Shanmuga, & Srinivas, 2012, p. 338).
- UV reflective chemical coating such as Lumacept (Jelden et al., 2017, p. 457) and Tismo-D(Cho, Woo, Chun, & Park, 2001, p. 1230) or having reflective surfaces.
- Chemical coating

Animals
- Visual interference (e.g. reflection, lighting)
- Olfactory interference (e.g. smoke or chemical)
- Auditory interference (e.g. high-frequency noise)
- Physical barriers/interference (e.g. fence, whipping)
- Enhanced physical barriers (e.g. spike walls)
- Source control (e.g. captivity)

Rain
- Partially blocking (e.g. roof, cave)
- Isolation (e.g. house)
- Source control (e.g. weather forecast)

References

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Appendix H List of Strutures for Human Activities

Portable	Pneumatic	Inflatable booth
	Foldable	Tent, umbrella
	Rigid	Incubator, stroller
Enclosure	Partition	Fence
	Natural barrier	Air wall, moat, tree hole
Buildings*	Masonry	Masonry wall, arch, vault, dome
	Form Active	Cable, tent, arch
	Vector Active	Truss, space frame, geodesic dome
	Section Active	Frame, slab
	Surface Active	Shell, folded plate

** Adapted from Misirlisoy, 2011, pp. 33-58*

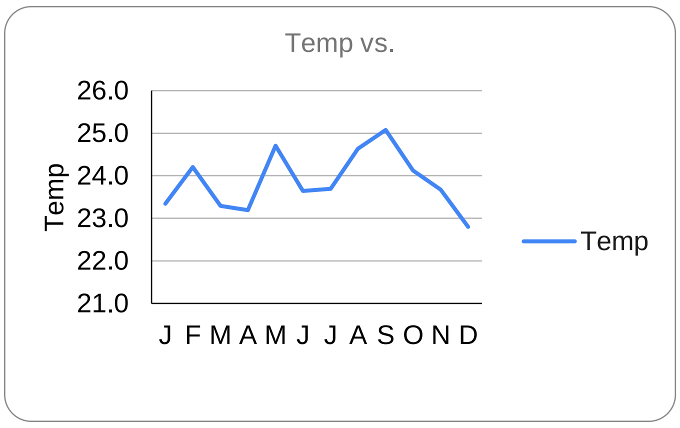
References

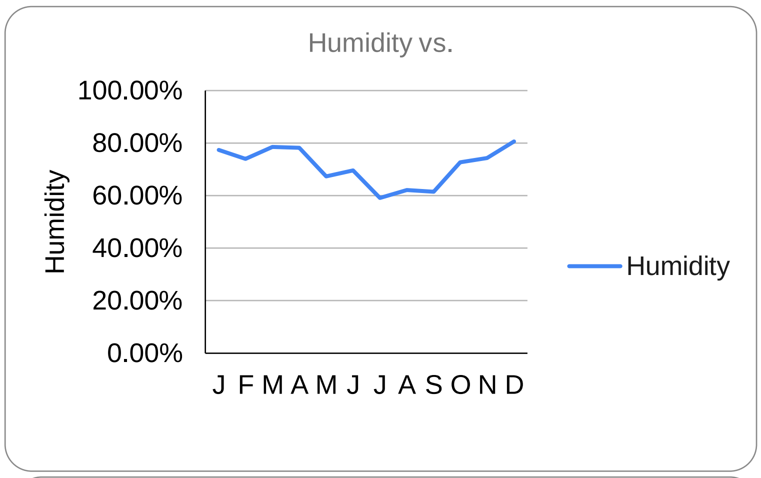
Misirlisoy, Damla. (2011). Analysis of the structure and design relationship between contemporary extensions and remodeled masonry buildings. 10.13140/RG.2.1.3340.4328.

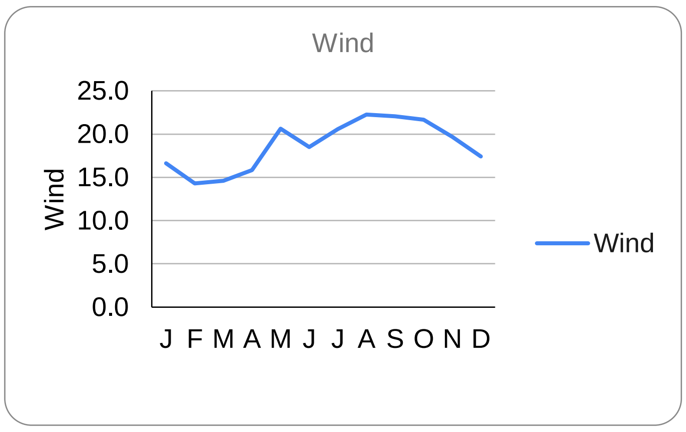
Appendix I Weather Data of Ukara

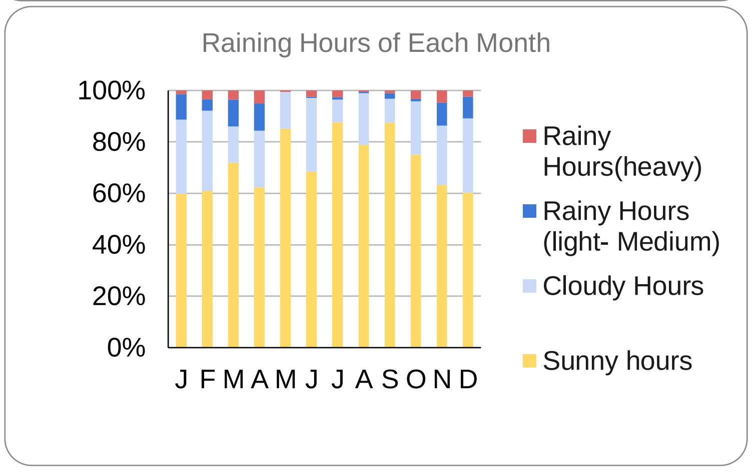
All Data were retrieved from https://www.timeanddate.com/weather/@149292/historic

	J	F	M	A	M	J	J	A	S	O	N	D
Temp	23.3	24.2	23.3	23.2	24.7	23.6	23.7	24.6	25.1	24.1	23.7	22.8
Humidity	77.33%	73.97%	78.53%	78.27%	67.26%	69.56%	59.12%	62.14%	61.51%	72.71%	74.34%	80.63%
Wind	16.6	14.3	14.6	15.9	20.6	18.5	20.6	22.3	22.1	21.7	19.7	17.4
Sunny hours	122	108	144	111	133	117	170	160	160	141	121	122
Cloudy Hours	59	55	28	39	22	49	17	41	17	39	44	58
Rainy Hours (light- Medium)	20	8	21	19	0	1	2	1	4	2	17	17
Rainy Hours(heavy)	3	6	7	9	1	4	5	1	2	6	9	5









Appendix J Comparison of Preservation Methods

Basic

Salting & Sugaringa

Kills microorganisms by the osmotic pressure difference or lowers the water activity[d]

Shelf life Very long
Cost Medium to high

Acidification (Pickling, fermentation)

Inhibit microorganisms by lowering the pH level[d]

Shelf life Long[c]
Cost Medium to high

Smoking

Inhibit microorganisms by exposing the antimicrobial actions of wood smoke[d] for over 12 hours (Smoke drying[c])

Shelf life Medium if properly stored[i]
Very long if dried or salted[c]
Cost Medium

Deep Frying

Destroy microorganisms and enzymes and reduce water activity of the food[e]

Shelf life Short[j]
Cost Low

Confit

Slow fry the food and store it in its own oil to prevent oxygen contact

Shelf life Medium
Cost Low to medium

Adding Biopreservatives[ab] or Artificial Preservatives

To prevent and limit the microbial growth in food[a]

Shelf life Long
Cost Medium to high

Flavor Generally Kept   Flavor Significantly Changed

Neutral

Freezing[c]

Low temperature slows down or stops the growth of microorganisms[d]

Shelf life Very long
Cost High

Chilling[c]

Low temperature slows down or stops the growth of microorganisms[d]

Shelf life Short to medium
Cost High

Long-term   Short-term

High-Tech

High-pressure Processing

Apply high pressure to the food for a while to kill the microorganisms[d]

Shelf life Medium
Cost High

Humectants

Inhibit the growth of microorganisms by adding humectants[g], such as sugar and salt, to lower the water activity[d]

Shelf life Medium
Cost Medium to high

Thermal Processing

Reduce the numbers of surviving microorganisms by heating the food, such as pasteurization and sterilization for low-acid food[d]

Shelf life Sterilization: long[c]
Pasteurization: Medium
Cost High

* sardine is low in acid[f]

Ohmic Heating

It is a process of heating the food by passing electric current[h]

Shelf life Long if dried
Cost High

Pulsed Electric Field Processing

Expose food to a pulsed high-voltage field for less than 1 second to kill the microorganisms[d]

Shelf life Medium
Cost High

Modified Atmosphere Packaging

Inhibit the rate of biodeterioration by modifying the air composition in the package[d]

Shelf life Medium to long
Cost High

Hurdle Technology

Apply two or more controlling factors to products in order to control or inhibit microbial growth[d]

Shelf life Depends
Cost Very high

Single/Multiple Controlling Factor(s)

Emerging Technology

[*] The shelf life is a relative estimation of processed fish

[a]Mogoşanu, Grumezescu, Bejenaru, & Bejenaru (2017). [b]Debaste, Flahaut, Penninckx, & Songulashvili (2018). [c]Joardder & Masud(2019). [d]Tucker (2016). [e]Oke, Idowu, Sobukola, Adeyeye, & Akinsola (2017). [f]KILINC, CAKLI, & TOLASA (2008). [g]METER Group (n.d.). [h]Kaur & Singh (2015). [i]Mhongole & Mhina (2012). [j]Reynolds (1993).

In terms of quality, in general, preservation methods that do not involve high heat, such as pasteurization, chilling, and freezing have lower-to-no nutrition loss than those that involve high heat (Joardder & Masud, 2019, pp. 141-144). As for fermented foods, research says (Srivastava, 2018, p. 9) that they are rich in nutritional values.

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Srivastava, R. K. (2018). Enhanced shelf life with improved food quality from fermentation processes. Journal of Food Technology and Preservation, 2(3), 8–14. Retrieved from https://www.alliedacademies.org/articles/enhanced-shelf-life-with-improved-food-quality-from-fermentation-processes.pdf

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Appendix K List of Requirements

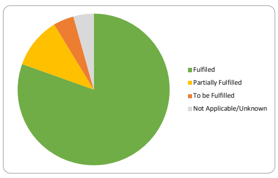
Category	#	Demand	#	Wish	Source	Validation comments
Performance						
	1	The drying solution must dry fish before 18:00 the same day			Inherited from Project Dagaa	to obtain a steady income, the fish must be sold every day. Also the fish must dry in one day otherwise it will rot and become chicken food
	2	The drying solution must protect the Dagaa from the rain			Inherited from Project Dagaa	then the change is bigger that it won't dry within a day and the shinyness is less when it becomes wet
	3	The fish out of the drying solution may not contain sand or dirt.			Inherited from Project Dagaa	The output may not contain sand or dirt coming from the ground which contaminate the catch
	4	All fish coming from the drying solution should be for human consumption			Inherited from Project Dagaa	Fish that is not dried in one day is chicken food, in order to achieve food secuirity all fish should be dried for human consumption
	5	The capacity of the drying solution should be at least 200 buckets			Adapted according to Upepo	People will only think the solution is interesting if it is big enough to make a differnce. we want to change the financial impact of dagaa and that only works for a big solution
	6	The drying solution should not allow animals contact (birds, goat, dog, cat)			Rephrased from Project Dagaa	Animals eating the fish causes post harvest losses, and it is not hiegenic.
	7	The product maintain the temperature around dagaa constantly between 35°C and 65°C			Literature Research	
	8	The product maintain the humidity around dagaa constantly between 10% and 40%			Literature Research	
	9	The quality of the fish should be better than sand drying			Sagar Energy solutions	
	10	The product must be self-sufficient in energy			Sagar Energy solutions	
			1	Rain does not infuence drying time and quality	Inherited from Project Dagaa	
			2	The drying solution fits all of the catch of one camp of 10 boats	Inherited from Project Dagaa	A large camp starts from 10 boats
			3	With perfect weather circumstances the fishermen still want to use the drying solution	Inherited from Project Dagaa	Quality should be better than on the sand
			4	The product should prevent heat losses as much as possible	Literature Research	
			5	The quality of the fish should be better than Upepo	Sagar Energy solutions	
Environment	11	The product must be able to endure temperatures between 15°C and 65°C			Context and drying method research	The lowest temperature in Ukara is 18, and the highest temperature for drying dagaa is recommemded to be below 64
	12	The product should be resistant to tropical rain and wind			Inherited from Project Dagaa	
	13	The product must be good for the climate on island Ziragula, Kasalazi and Ukara			Sagar Energy solutions	We start desiging for Ziragula and surrounding islands
	14	The drying solution fits all different climate types around lake victoria			Inherited from the wish of Project Dagaa	If it is modular, it can be used on islands. In the north they do not have a lot of sun, but a lot of wind.
	15	The product should utilize available natural resources as much as it is not harming the nature			Context and drying method research	To be sustainable and to save cost
Life in service	16	The product should function without repairs for at least 1 year when used daily for 12 hours			Inherited from Project Dagaa	
	17	Product should have a lifespan of at least 5 years when used daily for 12 hours			Inherited from Project Dagaa	the product will be the first in his generation, there will come different and better editions so the lifespan is not priority one
			6	The product should have a lifespan as long as possible	Inherited from Project Dagaa	
Maintenance	18	All subcomponents must be replacable by a certified technician			Inherited from Project Dagaa	a certified technician is someone who is educated about the product and knows how it is assebled and disassebled
	19	All maintainance can be executed on the islands			Inherited from Project Dagaa	
	20	repair service must be available including spare parts withing 48 hours			Inherited from Project Dagaa	
			7	All certified technicians must be locally trained	Inherited from Project Dagaa	As much employeement in Tanzania as possible
Target product cost	21	Using the drying solution will pay out more than using the current sand drying			Context Research	Increased income due to quality increase and loss save >= Rent of land + solution cost/rent
			8	breakeven time of the drying solution must be under 1 year	Inherited from Project Dagaa	Based on the lamps Sagar is selling people are willing to invest in something that pays out between 7 to 12 months.
			9	The production costs of the product should be as low as possible		
Transport	22	The drying solution can be transported (disassembled) to the islands			Inherited from Project Dagaa	
	23	The transportation from main land to the islands can be done with the current transportation methods			Inherited from Project Dagaa	
			10	The first prototype made in the Netherlands must be able to be transported to Mwanza.	Inherited from Project Dagaa	
Quantity	24	The drying solution can easily be scaled			Inherited from Project Dagaa	Should eventually be scalable for every island and dagaa capacity
			11	The drying solution needs to be modular so it fitst different islands and its climate types	Inherited from Project Dagaa	Islands have different climate and sizes
Product facilities	25	The drying solution must be fabricated in Tanzania as much as possible			Sagar Energy Solutions	Use imported components only if necessary
			12	Initial investment in the production should be as low as possible	Inherited from Project Dagaa	
Size & weight	26	The size of the drying solution should not take more space than the current sand drying			Inherited from Project Dagaa	
	27	the weight of the drying solution must be low enough to be transported by ferry			Inherited from Project Dagaa	
Aesthetic, appearance and finish						
			13	the drying solution must look robust	Inherited from Project Dagaa	A robust look makes people have trust in the product, should not look fragile
			14	The drying solution should have a modern look	Inherited from Project Dagaa	People here like new stuff, should look attractive to them
Materials	28	Parts produced of rubber, metal or plastic should be durable			Inherited from Project Dagaa	
	29	The fuel selection of the heater should not have higher impact than Charcoal			LCA	
	30	The material selection of the design should not have higher impact than Upepo			LCA	
			15	The number of components should be reduced by merging components with similar functions	Functional Analysis	
			16	The product is as biodegradable or recyclable as possible	Inherited from Project Dagaa	
			17	as much material as possible from the drying solution needs to come out of tanzania	Inherited from Project Dagaa	
Standards, rules and	31	The solution should meet governemental demands			Inherited from Project Dagaa	
			18	The government supports our drying solution	Inherited from Project Dagaa	
			19	the government changes the sand drying regulation based on our solution	Inherited from Project Dagaa	Chakuwata (fishers organization) told that this would be a possibility.
Ergonomics	32	The product must be understandable and usable by users regardless of their educational level			Rephrased from Project Dagaa	Most camp ladies do not have much education
	33	The user must be able to place the fish in and take the fish out of the drying solution			Inherited from Project Dagaa	
	34	processed fish than the current sand drying method			Rephrased from Project Dagaa	Working with the rake is though and gives camp ladies sore shoulders
			20	The product use should be as comfortable as possible	Inherited from Project Dagaa	
			21	The product should require as little preparative actions as possible per drying activity	Inherited from Project Dagaa	
			22	Users should not work in direct sunlight while using the drying solution	Inherited from Project Dagaa	The sun is hard to work in
Reliability	35	Chance of the product to fail because of production errors should be smaller than 5%			Inherited from Project Dagaa	Rule of thumb Erik Tempelman: 2% of the total amount of newly sold products may malfunction
	36	The product should be hard to copy for competition			Adapted from Project Dagaa	
Safety	37	The product must be fire-retardant				
	38	The product must not produce toxic fumes when burned				
	39	risks of injury should be low while assembling the drying solution				
	40	The product should not contain sharp edges which could lead to injuries				
Product policy	41	The product should not be powered with fossil energy			Inherited from Project Dagaa	
	42	if the product used additional energy it should be green			Inherited from Project Dagaa	
			23	The product should create as many jobs as possible	Inherited from Project Dagaa	Boost local employeement
Product Liability	43	The user must be given a 1-year warranty covering manufacturing defects.			Inherited from Project Dagaa	Sagar Energy Solutions
Sustainability	44	The drying solution should not produce harmful emmision to the environment			Inherited from Project Dagaa	
	45	the drying solution must not encourage overfishing			Inherited from Project Dagaa	We want to reduce post harvest losses, not encourage extra fishing.
	46	The impact of the product should not be more than Upepo			LCA	Carbon footprint, CED, ReCiPe

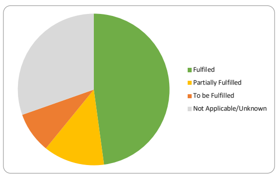
UpWind Achievement

Category	#	Demand	Status	#	Wish	Status	Note
Performance	1	The drying solution must dry fish before 18:00 the same day	Fulfilled (to be Validated)				According to the calculation (Appendix A), the drying will be finished around 4 hours during sunny days, 4~8 hours on rainy days (depending on the shifting frequency, heat loss, and dehumidification capacity. the Max is just doubling the time to dry on Sunny days). Assuming the drying process takes place from 8 am every day, it will be finished at 12pm on sunny days, at 4pm on rainy days.
	2	The drying solution must protect the Dagaa from the rain	Fulfilled and Validated				Closed greenhouse
	3	The fish out of the drying solution may not contain sand or dirt.	Fulfilled (to be Validated)				
	4	All fish coming from the drying solution should be for human consumption	Fulfilled (to be Validated)				
	5	The capacity of the drying solution should be at least 200 buckets	Fulfilled and Validated				UpWind can be scaled up by building more UpWinds side by side (Mabye the walls between UpWinds can be omitted)
	6	The drying solution should not allow animals contact (birds, goat, dog, cat)	Fulfilled and Validated				Closed greenhouse
	7	The product maintains the temperature around dagaa constantly between 35°C and 65°C	Fulfilled (to be Validated)				According to the simulation, the temperature stays above 35 degree Celsius during sunny days. When the temperature is raised to 35 degree, the humidity would be lower than 40%. And the humidity will be maintained at this level through dehumidification and exchanging with outdoor air when needed. During rainy days, the temperature and humidity will be controlled by heat pump and the desiccant layers. However, the effect should be tested.
	8	The product maintains the humidity around dagaa constantly between 10% and 40%	Partially Fulfilled				According to the calculation, during sunny days, assuming the ambient relative humidity is 65%, the air inside the greenhouse should be able to 25% (and lower, due to the desiccant layer). The humidity during rainy days depends on the shifting frequency, heat loss, and dehumidification capacity. Testings should be done to determine whether this can be fulfilled.
	9	The quality of the fish should be better than sand drying	Fulfilled and Validated				Validated by Project Dagaa
	10	The product must be self-sufficient in energy	Fulfilled and Validated				PV panels
				1	Rain does not infuence drying time and quality	Partially Fulfilled	In order to lower the cost, the heat pump is shared by two UpWinds. Therefore, the drying time is estimated to be longer than on sunny days. UpWind aims to save the harvest loss on rainy days.
				2	The drying solution fits all of the catch of one camp of 10 boats	Fulfilled and Validated	One UpWind can accommodate 390 Kg of wet dagaa. According to Project Dagaa, the average catch of a boat is 500 kg. Therefore, it takes 13 UpWinds to accommodate a medium camp's catch (10 boats).
				3	With perfect weather circumstances the fishermen still want to use the drying solution	Fulfilled (to be Validated)	UpWind dries fish faster and brings more profit than sand drying for fishing camps. However, it still needs to be find out whether this is attractive to the local fishing camps.
				4	The product should prevent heat losses as much as possible	Fulfilled (to be Validated)	The heat exchanger, heat storage, and insulation layers help to prevent heat losses.
				5	The quality of the fish should be better than Upepo	Not Applicable/Unknown	Unknown
Environment	11	The product must be able to endure temperatures between 15°C and 65°C	Fulfilled (to be Validated)				Theoretically, all materials used in UpWind can withstand this temperature range; however, practically, it still should be validated.
	12	The product should be resistant to tropical rain and wind	Fulfilled (to be Validated)				Theoretically, the Quonset greenhouse should be able to tolerant wind and rain because of its acrhed shape.
	13	The product must be good for the climate on island Ziragula, Kasalazi and Ukara	Fulfilled (to be Validated)				The heat pump provides heat on rainy days; therefore,UpWind should be suitable for different climates.
	14	The drying solution fits all different climate types around lake victoria	Fulfilled (to be Validated)				UpWind should be functional in every climate conditions, however, the more the heat pump is used, the higher cost it will be
	15	The product should utilize available natural resources as much as it is not harming the nature	Fulfilled and Validated				UpWind utilizes the heat, wind, and sand of the islands. And utilizes the air during sunny days.
Life in service	16	The product should function without repairs for at least 1 year when used daily for 12 hours	Partially Fulfilled				The lifespans of the materials are all longer than 1 year, mostly more than 3 years, some even 10-20 years. It fulfilled the requirement in terms of the durability of the material; however, the need for repair is unknown. Nevertheless, this requirement is unrealistic, although it can be evaluated by repetitive testings, it is still hard to predict the potiential damage caused by the actual use.
	17	Product should have a lifespan of at least 5 years when used daily for 12 hours	Fulfilled (to be Validated)				Although some components/materials may have shorter lifespan, it can still be repaired due to the modularity of UpWind
				6	The product should have a lifespan as long as possible	Fulfilled (to be Validated)	The repairablility of UpWind
Maintenance	18	All subcomponents must be replacable by a certified technician	Fulfilled (to be Validated)				UpWind's components are replacable and repairable due to its modularity. Although the heat pump might need higher skill to repair, it is still expected to be acquirable by proper training.
	19	All maintainance can be executed on the islands	Fulfilled (to be Validated)				All parts are modularized so that the repair work can be done on the islands
	20	repair service must be available including spare parts withing 48 hours	Fulfilled (to be Validated)				If the service providers can stock some spare components, especially for PV Panels and Heat pump, this requirement can be achieved.
				7	All certified technicians must be locally trained	Not Applicable/Unknown	The training of refrigeration technicians should be discussed with a refrigeration company.
Target product cost	21	Using the drying solution will pay out more than using the current sand drying	Fulfilled and Validated				According to the cost-profit estimation, the fishing camps will have more profit than before
				8	breakeven time of the drying solution must be under 1 year	To be Fulfilled	The payback period is about 5 years due to the high initial cost of PV panels and the heat pump. If the service provider can lower the cost or acquire subsidies, the payback period is expected to be shorter.
				9	The production costs of the product should be as low as possible	To be Fulfilled	
Transport	22	The drying solution can be transported (disassembled) to the islands	Fulfilled (to be Validated)				Due to the modularity of UpWInd, the parts can be assembled on the islands. And the assembly is also simplified by only using bolts and screws.
	23	The transportation from main land to the islands can be done with the current transportation methods	Fulfilled (to be Validated)				The biggest part of UpWind is the hoops (W 4m L2.4m), a medium boat should be able to transport it.
				10	The first prototype made in the Netherlands must be able to be transported to Mwanza.	Not Applicable/Unknown	The usable parts will be transported to the office in Rotterdam for future studies.
Quantity	24	The drying solution can easily be scaled	Fulfilled and Validated				UpWind can be scaled up by building more UpWinds side by side.
				11	The drying solution needs to be modular so it fits different islands and its climate types	Fulfilled and Validated	
Product facilities	25	The drying solution must be fabricated in Tanzania as much as possible	Fulfilled and Validated				Except PV panels and the heat pump, all parts can be fabricated locally.
				12	Initial investment in the production should be as low as possible	Partially Fulfilled	Though the initial cost is high, but the monthly investment is not as high.
Size & weight	26	The size of the drying solution should not take more space than the current sand drying	Fulfilled and Validated				It takes 40% less than before
	27	the weight of the drying solution must be low enough to be transported by ferry	Fulfilled and Validated				Due to the modular feature of UpWInd, it can be transport seperately
Aesthetic, appearance and finish				13	the drying solution must look robust	Not Applicable/Unknown	Unknown
				14	The drying solution should have a modern look	Not Applicable/Unknown	Unknown
Materials	28	Parts produced of rubber, metal or plastic should be durable	Fulfilled (to be Validated)				The lifespans of the materials are all longer than 1 year, mostly more than 3 years, some even 10-20 years. It fulfilled the requirement in terms of the durability of the material;
	29	The fuel selection of the heater should not have higher impact than Charcoal	Fulfilled (to be Validated)				The heat pump uses renewable energy, although the increased impact of its materials should be further studied.
	30	The material selection of the design should not have higher impact than Upepo	Fulfilled and Validated				The net are switched to retired fishing nets, the charcoal fuel is replaced by green energy, and the rest of the materials remain the same as Upepo
				15	The number of components should be reduced by merging components with similar functions	Fulfilled and Validated	Harvesting tool is merged into the drying nets.
				16	The product is as biodegradable or recyclable as possible	Fulfilled (to be Validated)	
				17	As much material as possible from the drying solution needs to come out of Tanzania	Fulfilled and Validated	Except PV panels and the components of the heat pump, all materials are available in Tanzania
Standards, rules and regulations	31	The solution should meet governemental demands	To be Fulfilled				The regulation should be discussed with the government to set a limited amount of UpWind on one island. Other regulations should also be studied or discussed with the goverment.
				18	The government supports our drying solution	Not Applicable/Unknown	Unknown
				19	the government changes the sand drying regulation based on our solution	Not Applicable/Unknown	Unknown
Ergonomics	32	The product must be understandable and usable by users regardless of their educational level	Fulfilled (to be Validated)				According to the user test, the drying process is a skill-less task. It is expected to be easy for the actual users as well.
	33	The user must be able to place the fish in and take the fish out of the drying solution	Fulfilled (to be Validated)				According to the user test, all users of different height group can perform the task. although It can be improved.
	34	The operation of the drying solution must cause a lower physical effort per unit of processed fish than the current sand drying method	Not Applicable/Unknown				According to the user test, it is not a heavy task. However, it is marked unknown without testing with actual users
				20	The product use should be as comfortable as possible	Fulfilled (to be Validated)	According to the user test of the interaction inside the greenhouse setup, none of the participants stated that they had perceived any oppression during the test. Some participants even mentioned the brightness of the setup gave them an open-space perception.
				21	The product should require as little preparative actions as possible per drying activity	Partially Fulfilled	It has more steps in terms of drying than sand drying.
				22	Users should not work in direct sunlight while using the drying solution	Fulfilled and Validated	The PE film block the UV of the Sun.
Reliability	35	Chance of the product to fail because of production errors should be smaller than 5%	Not Applicable/Unknown				
	36	The product should be hard to copy for competition	Fulfilled (to be Validated)				It is hard to evaulate whether it is easy to be copied or not, but the heat exchanger, heat pump, wind-driven fans, and drying nets should require some more effort than mere wood works.
Safety	37	The product must be fire-retardant	To be Fulfilled				PE film and wood is not fire-retardant, but the alternative solution of this requirement is to provide a standard escape procedure and fire extinguishing procedure to the users and the service providers.
	38	The product must not produce toxic fumes when burned	Partially Fulfilled				Burning PE film and the refrigerant are not non-toxic
	39	Risks of injury should be low while assembling the drying solution	Fulfilled (to be Validated)				Only bolting and screwing is required for assembly, which means welding, cutting, and sawing is involved.
	40	The product should not contain sharp edges which could lead to injuries	Partially Fulfilled				The working areas do not have sharp edges. However, the wind-driven fan might post some danger to the users if trespass to the non-working areas.
Product policy	41	The product should not be powered with fossil energy	Fulfilled and Validated				UpWind is powered by PV panels
	42	if the product used additional energy it should be green	Fulfilled and Validated				UpWind is powered by PV panels
				23	The product should create as many jobs as possible	Fulfilled and Validated	It secures the job opportunities by introducing a two-worker operation. And creates jobs such as technicians and janitors.
Product Liability	43	The user must be given a 1-year warranty covering manufacturing defects.	Fulfilled and Validated				The cost-profit estimation is made with depreciation, therefore, the rent already includes maintenance fee for the service provider.
Sustainability	44	The drying solution should not produce harmful emmision to the environment	Fulfilled (to be Validated)				This requirement is not realistic, but UpWind aims to reduce the emission throughout the design.
	45	the drying solution must not encourage overfishing	Fulfilled (to be Validated)				A limited amount of UpWind will be set up according to the current situation. And it will be discussed with the goverment.
	46	The impact of the product should not be more than Upepo	Partially Fulfilled				Many features of UpWind are made to reduce its impact, however, the actual impact should be further studied.

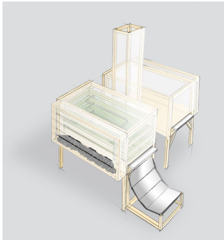
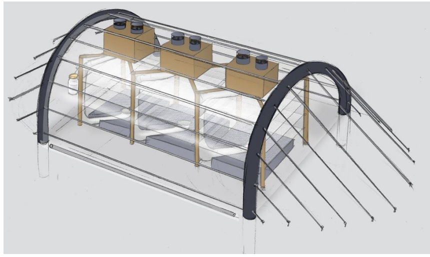
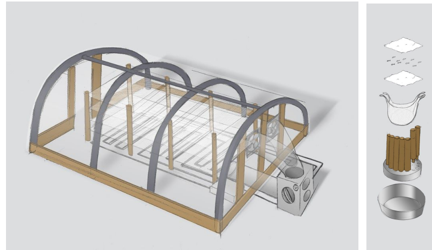
Total amound of requirements	46
Fulfiled	37
Partially Fulfilled	5
To be Fulfilled	2
Not Applicable/Unknown	2

Total amound of requirements	23
Fulfiled	11
Partially Fulfilled	3
To be Fulfilled	2
Not Applicable/Unknown	7





Appendix L Specifications and Evaluation of Three Concepts

	Oven	Cable	Heat pump
			
Dimensions (W/L/H)	Single oven(m): 1.6 x 2.1 x1.2 plus 0.4 leg height Atria facade(m): 0.25 x 2.1 x 1.2 Chimney(m): 0.7 x 0.7 x 2.6 Single tray(m): 1.5 x 2 x 0.05 oil drum(m): 0.9 x 0.6 x 0.6 Reflector(m): 0.8 x 0.8 x 0.4 Metal pieces(m): 0.8 x 0.25 x 0.05 Wood beam thickness(cm): 5 x 5 Inlet area(m^2): (0.02+0.02+0.04+0.04) x 1.8 x 2 =0.432 Outlet area(m^2): 0.7 x 0.7 = 0.49	Body(m): 4 x 12 x 3 Single net(m): 2.5 x 3.3 Sticks(cm): ⌀7 x 200 Heat exchanger(box, cm): 35 x 70 x 45 Heat exchanger(inlet&outlet, cm): ⌀30 x 30 Fan(cm): 30 x 30 Single duct(cm): ⌀30 x 500 Oil drum(m): 0.9 x 0.6 x 0.6 (place two under one section)	Body(m): 4 x 12 x 3 Single net(m): 2.5 x 3.3 Sticks(cm): ⌀7 x 160 Heat pump(Evaporator): 45 x 70 x 45 Single duct(cm): ⌀40 x 150 Fan(cm): 45 x 45 Salting (porous base, cm): 170 x 170x 10, holes for sticks ⌀ 4 Canvas(m): 4 x 0.8 Salting plate(m): 1.8 x 1.8 x 0.1 Salting sticks(cm): ⌀7 x 80 (shared component)
Capacity	Drying & Smoking: 96 m^2 (4 sets i.e. 8 ovens, 32 trays)	Drying: 100m^2 (12 nets) Fermentation: 100m^2 (22 Jars, 25L)	Drying: 100m^2 (12 nets) Salting: 92.5m^2 (32 layers, 2cm dagaa + 0.5cm salt)
Material ***Default (regular + alternative)*** 80% Sunny 20% Rainy Assuming the net profit of active thermal drying < that of the alternative method ***Optional (active heating)*** > 50% Rainy Assuming the net profit of active thermal drying > that of the alternative method Assuming the operational cost of heating < the cost of the alternative method	***Default*** Body structure - Wood beams/planks Cover - PE film Openings - Steel wire Mesh - Reused old nets Door hinge -Iron Reflector - Reflective tape or Aluminum foil Heating coil - Aluminum Fan (90w x4) - steel, aluminum, motor Power supply - 370w PV panel x 1 + battery Heat conduction piece - Aluminum Fuel - Solid biomass Heater - Reused metal oil drum x 8 Smoke inlet - Aluminum	***Default*** Body structure - Steel plates Cable - Steel wire Cover - PE film Wiggle wire - Alu, steel Sticks - Bamboo + steel hook Mesh - Reused old nets + steel wire Duct - Stainless steel Heat exchanger - Wooden box, aluminum chimney, aluminum wind cup, aluminum fan blade, aluminum crossflow plate Fan (120w x3) - steel, aluminum, motor Power supply - 370w PV panel x 1 + battery Heat storage/fly repellent/fermentation - glass jar Table layer - wood & steel wire Fermentation ingredients - salt and spices ***Optional*** Fuel - Solid biomass Heater - Reused metal oil drum x 6	***Default*** Body structure - Steel pipes + wood plank Cover - PE film Wiggle wire - Alu, steel Sticks - Bamboo + steel hook Mesh - Reused old nets + steel wire Fan - steel, aluminum, motor Duct - stainless steel Moisture absorber - Rock salt Salting - rock salt Salting bowl & base - Aluminum Power supply - 370w PV panel x 1 ***Optional*** Pipes- stainless steel, aluminum or copper Heat pump (1kW x 1) - stainless steel (fittings, valves, and coupling), ammonia (working fluid) Power supply - 370w PV panel x 4 + battery

Affordability (5) Whether the concept is cost-efficient, ie. having a high ratio of the drying effect to the sum of the total cost. The effectiveness is measured by its capacity (versus occupied space), drying time (inside temperature, humidity, and airflow rate) and shelf-life of the alternative method. The cost includes materials, components, and labor. Upepo: [9+6(8,9,1)]/2= 7.5	**8** Cost(8): coil, metal pieces Effectiveness(8): [capacity: 9 / drying time (sunny days): 7 / drying time (rainy days with heating): 8 / shelf-life of the alternative method: 8]	**7.5** Cost(7): (heat exchanger, jars, ingredients, duct, fan Effectiveness(8): [capacity: 8 / drying time (sunny days): 8 / drying time (rainy days with heating): 8 / shelf-life of the alternative method: 8]	**7** Cost(6): heat pump, pipes, salt, duct, fan, PV panel & battery Effectiveness(8): [capacity: 8 / drying time (sunny days): 8 / drying time (rainy days with heating): 8 / shelf-life of the alternative method: 8]
Availability (3) To what extent the concept can be locally manufactured, i.e. the availability of its materials and the required manufacture machinery and skill. Upepo: [9+9]/2-1= 8	**7.5** - Manufacture(9): Alu. coil, metal pieces - Material(8): biomass fuel - Component(-1): PV panel & battery	**6.5** - Manufacture(7): Heat exchanger, steel wire - Material(8): bamboo, biomass fuel - Component(-1): PV panel & battery	**5.5** - Manufacture(8): Heat pump(pipes), steel wire - Material(7): bamboo, biomass fuel, rock salt - Component(-2): Heat pump(evaporator, condenser, valve), PV panel & battery
Reliability (4) Whether the concept is durable, easy to maintain, and can be repaired locally. This is measured by the lifetime of material, mechanism, and modularity of the whole concept(in terms of maintenance) Upepo: [8+8]/2= 8	**7** - Material(8): (shorter) PE film, net - Modularity(6): Openings, structure	**8** - Material(7): (shorter) heat exchanger, PE film, net - Modularity(9): hanger	**7.5** - Material(6): (shorter) heat pump, PE film, net - Modularity(9): hanger
Sustainability (3) Whether the concept has lower sustainability impacts than Upepo. And how is the performance on 3Rs, i.e. Reduce, reuse, and recycle. Upepo: [8+6]/2= 7	**8.5** - Impact(8): burning wood/charcoal - 3Rs(9): oil drum, net, charcoal, Alu. steel	**8** - Impact(7): burning wood, more components - 3Rs(9): oil drum, net, charcoal, jar, Alu. steel	**8** - Impact(7): more components (heat pump, PV panel) less operational pollution - 3Rs(9): oil drum, net, charcoal, jar, Alu. steel
Acceptability (1) How is the acceptance of intended users towards the concept? It can be measured by communicating with stakeholders and conducting user tests.	**7** - Stakeholders(7) - Users(?)	**5** - Stakeholders(5) - Users(?)	**9** - Stakeholders(9) - Users(?)
Full point = 160	**123**	**118**	**114.5**

Appendix M Use Scenarios of Three Concepts

Use Scenario of Concept Oven

1. Users bring the fish to the oven
2. Remove all trays from the oven
3. Spread the fish onto the trays
4. Install all trays back to the oven

Sunny

5. Adjust the reflectors to the right angle

Rainy

5-1. Install the burners
5-2. Refill the fuel to the wood burner
5-3. Set fire and burn

6. Check dryness of each layer
7. Remove all trays from the oven
8. Pour and sweep the dried dagaa into the buckets

Use Scenario of Concept Cable

1. Users bring the fish inside the greenhouse

Sunny

2. Open the lid of the charcoal dehumidifier

Rainy

2-1. Refill the fuel to the wood burner
2-2. Set fire and cover the lid

3. Place the first net in place.
4. Take the bucket.
5. Spread the fish with hands onto the layer
6. hang the next layer.
7. Repeat step 5 to 6 until 4 layers are done
8. Check the dryness of each layer
9. Remove the net from the poles
10. Wrap the fish with the net
11. Pour the fish into the buckets
12. Repeat 9-11 until 4 layers are done

Use Scenario of Concept Heat Pump

1. Users bring the fish inside the greenhouse
2. Place the first net in place.
3. Take the bucket.
4. Spread the fish with hands onto the layer
5. Hang the next layer.
6. Repeat step 4 to 5 until 4 layers are done

Sunny

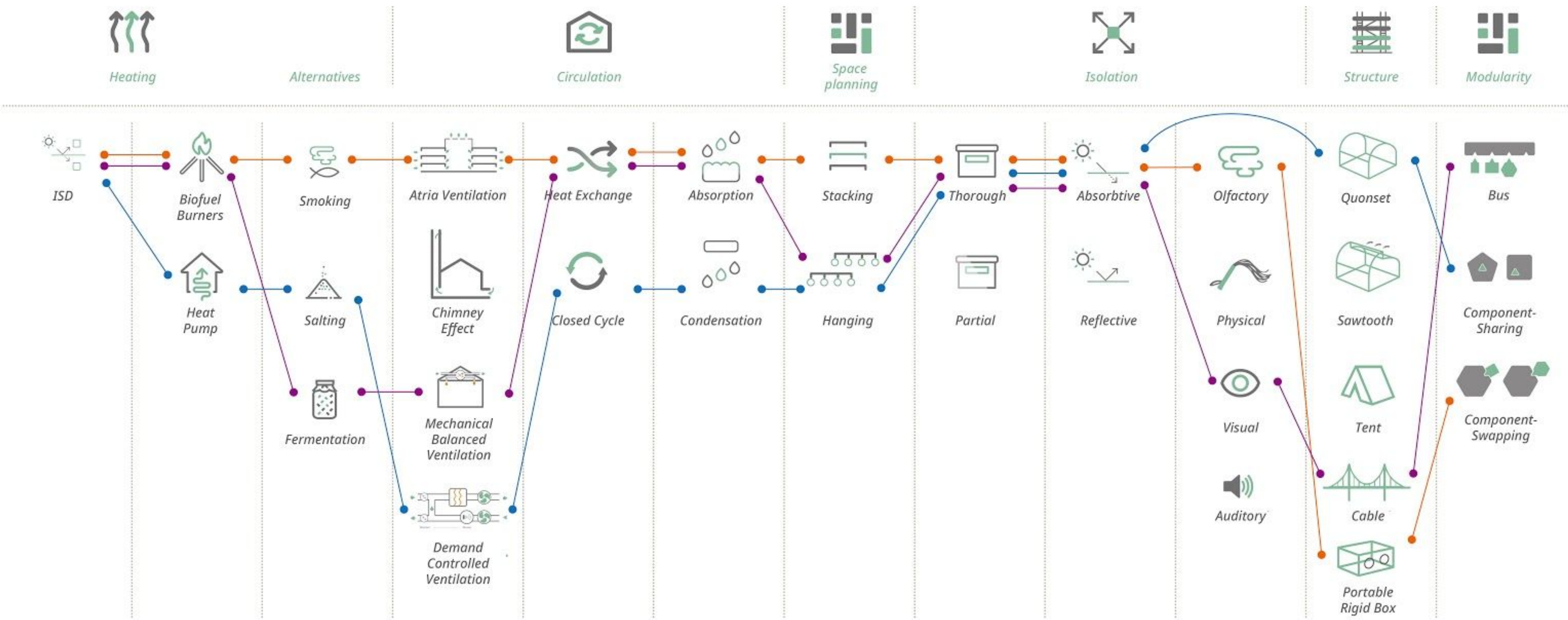
7-1. Switch the fan on
7-2. Place the dehumidifier
7-3. Check the hygrometer constantly
7-4. Open the valve to let fresh air in once the humidity is higher than outside humidity
7-5. Replace the dehumidifier.

Rainy

7. Switch the heat pump on

8. Check the dryness of each layer
9. Remove the net from the poles
10. Wrap the fish with the net
11. Pour the fish into the buckets
12. Repeat 9 to 11 until 4 layers are done

Appendix N Re-Evaluation of Morphological Chart



The evaluation basically uses the same criteria but without weight and acceptability (as it's considered minor). The criteria are adjusted based on the subsystem, such as adding/removing some criteria. The description fields explain the reason/main factors of the score.

In order to have a more accurate estimation, a 1-7 scale is used. 1 Very bad 2 bad 3 slightly bad 4 neutral 5 slightly good 6 good 7 very good.

A total score difference of (0-3) points from the highest score is the acceptable range, more than 4 is then defined as significantly different.

Heating

Efficiency is split from affordability as it is considered important.

	Biofuel Burners		Heat Pump	
Affordability	6	Low cost of the body, medium cost of fuel	3	High initial cost, medium operational cost
Efficiency	5		7	More efficient than other heaters
Availability	4	Shortage of Fuel, easy access to the building material	2	access to a heat pump(uncertain)
Reliability	7	Robust	4	Delicate & require skill for repair
Sustainability	3	Burning of fuel, easy production	5	Local operational energy consumption, complicated production, transport, and long pipes
Total	25		21	

If the initial cost can be lower, and if the robustness of the system can be addressed, these two options show similar opportunities.

Circulation

Efficiency (rephrased as effectiveness in this case) is split from affordability as it is considered important.

	Atria Ventilation	**Chimney Effect**	**Mechanical Balanced Ventilation**	**Demand controlled Ventilation**
Affordability	6 (building material)	7 (building material)	5 (fan, duct, energy)	4 (sensors, fan, duct, energy)
Effectiveness	4 (surface airflow, wind-direction-dependent)	4 (more flexibility in terms of wind direction, but less control of the airflow direction)	6	7
Availability	7	7	6 (fan)	5 (fan & sensors)

Reliability	7	7	6	5 (delicate and require skills for repair)
Sustainability	7 (building material)	7 (building material)	6	5
Total	31	32	29	26

Although atria ventilation and chimney effects have higher scores, the effectiveness performance is too low. It is suggested to be improved by using mechanical ventilation. The demand-controlled ventilation involves sensors that are absent in TZ, so the score is relatively low.

The heater and ventilator are more specific, so it can be discussed in detail. But there's too much uncertainty in heat recovery and dehumidifiers, the evaluation is more of a rough estimation. While evaluating this feature the heat loss and humidity of the supply air are taken into account.
The closed cycle requires a dehumidifying function while for heat exchange it is optional, thus the score of the closed-cycle system is merged with the dehumidifying function.

	Heat Exchange		**Closed Cycle (Absorption/Condensation)**	
Affordability	6	conductor	6/4	Only the absorption layers are needed/Electric product
Effectiveness	4	Highly dependent on the conductivity and outdoor humidity	6/7	It greatly keeps the heat but considering the humidity
Availability	7	Manufacturing of the heat exchanger can be simplified	6/3	Depends on the filter material
Reliability	6	Less mechanical components involved	6/4	Depends on the filter
Sustainability	6	Depending on the conduction piece, but in general, the production is not difficult and the use of the material is not much.	6/4	Choosing a reusable filter can improve its sustainability/Electricity consumption and the complexity to build the system lowers its sustainability score. But heat loss prevention increases its score.
Total	29		30/22	

A closed-cycle system is highly dependent on the dehumidifying filter, to achieve the score a suitable dehumidifying filter should be chosen. If a condensation method with higher availability, reliability, sustainability scores can be found, it may still stand a chance.

	Absorption		**Condensation**	
Affordability	6	Depending on the material (assuming a medium performance material is used without an extra dryer for it)	4	Electric product
Efficiency	5	medium performance	7	
Availability	6	medium performance material like charcoal, baking soda, coffee powder	3	Electric product
Reliability	6	The filter can be reused until it is worn out.	4	The machine may need more maintenance
Sustainability	6	Reusable filter and no electricity consumption. Its sustainability impact depends on the material choice	3	Electricity consumption and the complexity to build the system.
Total	29		21	

The use of a heat pump increases its performance on the general score on heat recovery and humidity control due to its multifunction.

	Heat Pump	**Closed Cycle (Condensation)**	**Condensation**	
Affordability	3+1	4+1	4+1	Sharing components
Efficiency/Effectiveness	7+1	7+1	7+1	
Availability	2+1	3+1	3+1	Electric product
Reliability	4+1	4+1	4+1	The machine may need more maintenance

Sustainability	5+1	4+1	3+1	Electricity consumption and the complexity to build the system.
Total	26	27	26	

Although the scores are still slightly lower than the other options after adding some extra points, the score difference is within an acceptable range (2-3points). It is hard to estimate how much it adds. So I added one point to each criterion for component sharing credit.

Space Saving

	Stacking		**Hanging**	
Affordability	7	Single material, simple	6	Multiple materials, complex
Efficiency	5	Less flexibility	7	Helps dagaa collection, more freedom in using vertical space
Availability	6	Simple materials and production	5	Depends on the material, it has a higher possibility to be unavailable.
Reliability	7	robust	6	Complex system might be more fragile
Sustainability	6	Reused net + wood	5	Reused net + Steel
Total	31		29	

Not much difference was found in the space Saving subsystem.

Isolation

As partial isolation is hard to perform heat recovery, only thorough isolation was chosen.

	Absorptive		Reflective	
Affordability	7	Usually cheap, e.g. plastic	4	Metal/reflective coating
Efficiency	6	Traps the radiation heat inside. But still allows some UV entry.	4	Absorb radiation heat and transfer it through convection and conduction, assuming this way is less efficient(TBD)
Availability	6		6	
Reliability	5	3-year Lifetime	6	Long lifetime
Sustainability	5	Though plastic is harming the environment but considering the recycling credit and density(weight) difference, it is more sustainable than steel	4	
Total	29		24	

The reflective cover seems not to be efficient for solar heat collection.

While comparing the repellent methods, the simplest construction of each method was considered.

	Olfactory	Physical	Visual	Auditory
Affordability	4 (fuel)	5 (moving object)	6 (it can be simple)	5 (can be simple, but it still needs some mechanism)
Effectiveness	7	6	5	6 (TBD)
Availability	4 (short of fuel)	6 (simple mechanism)	7	6 (simple mechanism of making noise)
Reliability	7	5 (mechanism needs maintenance)	6	5 (mechanism needs maintenance)
Sustainability	2 (fuel burning)	5 (more material)	6	5 (more material)
Total	24	27	30	27

Structure

	Quonset	Sawtooth	Tent (portable)	Cable	Portable Rigid Box
Affordability	6 (little material)	5 (compare to Quonset it's more complicated)	6 (less material)	7 (less material)	4 (solid and heavier)
Adaptability (for heat & circulation)	6 (air infiltration issue)	3 (specific wind direction, can't prevent heat loss)	5 (harder to be airtight)	5 (harder to be airtight)	7 (airtight)
Availability	7	6 (more complicated to manufacture)	7	5 (skill required for construction)	6
Reliability	6 (short lifetime of the cover, high modularity)	5 (short lifetime of the cover, high modularity)	4 (lightweight thus sensitive to wind)	5 (skill required for Maintenance)	5 (lack of modularity)
Sustainability	5 (more material than cable)	6	6	6	4 (more material)
Total	30	25	28	28	26

Conclusion

Some remarks of the combination are made:

1. Atria ventilation/chimney effect can combine some mechanical ventilator to improve its effectiveness
2. Closed-cycle should use absorption as its dehumidifying feature. However, because of the nature of heat pumps, the combination of its circulation is suggested to be "closed-cycle" plus "condensation".
3. The dehumidifying options for Heat exchange are optional.
4. The air circulation(airflow direction) and space saving should complement each other

Appendix O Heating and Circulation Iteration 01

Goals

1. Utilize natural ventilation (chimney effect and natural ventilation) and study its effectiveness (Airspeed, Air distribution)
2. Add a modular component: humidity absorber (Hygroscopic dehumidification: solid desiccants like desiccator wheels or liquid desiccants) for those places that do not need a heater
3. Utilize natural heat to reduce the energy consumption to warm up the dry air

Parameters

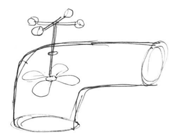
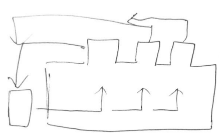
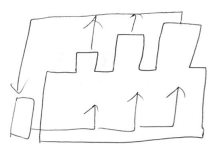
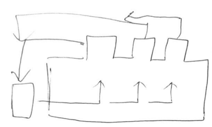
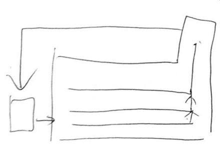
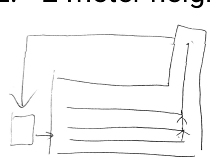
The following table shows the parameters that might affect the heating and circulation performance.

Component	Parameter	Component	Parameter
Heat Pump	Location	Outlet Opening	Location
	Dimension		Dimension
	Specs (power and material)		Specs (form and material of duct)
Greenhouse	Location	Chimney	Location
	Dimension		Dimension
	Specs (material)		Specs (material and amount)
Inlet Fan	Location	Racks	Location
	Dimension		Dimension
	Specs (power, material and amount)		Specs (Rack Layer Height and amount)
Inlet Opening	Location	Heat Exchanger	Location
	Dimension		Dimension
	Specs(form and material of duct)		Specs (number of layers and material)
Outlet Fan	Location		
	Dimension		
	Specs (power and material)		

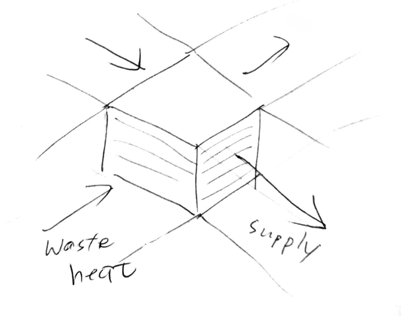
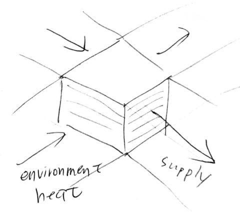
Ideation

The chosen ideas were divided into two groups, concept group, and simulation group. The effects of the simulation group were evaluated by flow simulation.

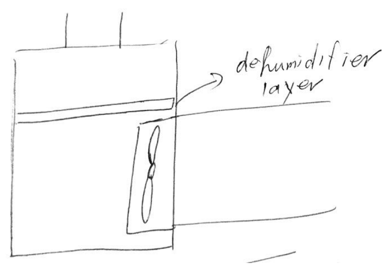
Utilize natural ventilation

Chosen Ideas	Description	Variations for simulation (Parameters adjustment)	Note
Wind-Driven Fan (Concept/simulation group) 	Utilize the natural wind to drive the internal airflow	The height of the fan was adjusted to check the effect on airflow. 1. Fans at low positions 2. Fans at high positions	The embodiment of the design was not tested in this iteration. But the effect on airflow was tested by simulation.
Chimney effect - Vertical airflow (Simulation group) 	Create three upward internal airflow by utilizing the chimney effect.	The heights of the chimneys were adjusted to check the effect on airflow. 1. Uneven height  2. Even height 	
Chimney effect - Horizontal airflow (Simulation group) 	Create laminar internal airflow by utilizing the chimney effect.	The height of the chimney was adjusted to check the effect on airflow. 1. 1-meter height  2. 2-meter height 	

Utilize natural heat

Chosen Ideas	Description	Note
Heat exchanger (concept group) 	To restore the heat from the exhaust air.	The original idea was to use the natural heat of the environment, but may not work during rainy days. 

Add a modular component: humidity absorber

Chosen Ideas	Description	Note
Desiccant layer (concept group) 	Absorb the humidity from the air.	Another idea is to put the desiccant inside the drying chamber, however, without air blowing, the effect might be less. 

Prototyping

Simplified 3D models of the simulation group were made in Solidworks for airflow study.

Evaluation (Simulation)

Vertical Airflow

To begin with, the internal air flow was simulated. It was expected that the heating elements on the ground (Fig. 1) would create vertical airflows, however, the simulation (Fig. 2) showed that the effect is not as significant as expected. Therefore, the heating elements were then integrated into the air blower (Fig. 3). And this change also increases the overall temperature inside the greenhouse (Fig. 4 & 5).

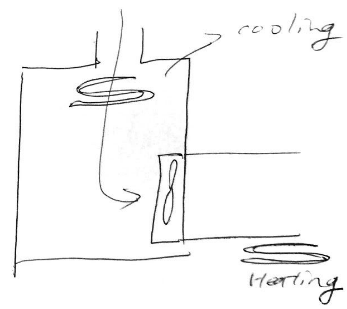


Figure 1. Ground Heating Elements

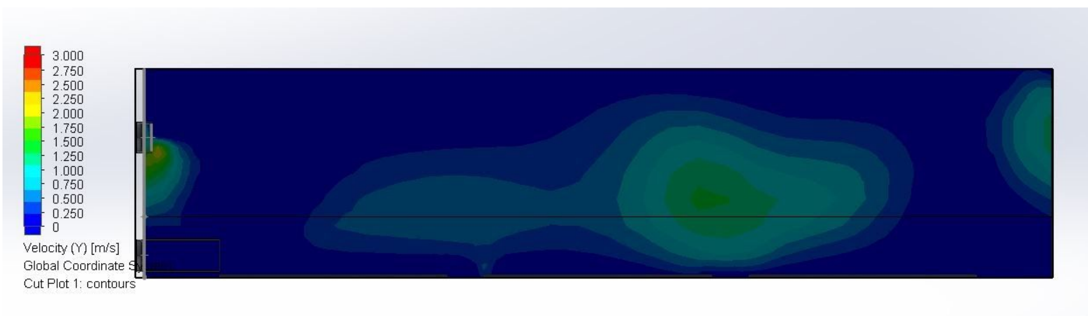


Figure 2. Velocity Y of Concept Heat Pump

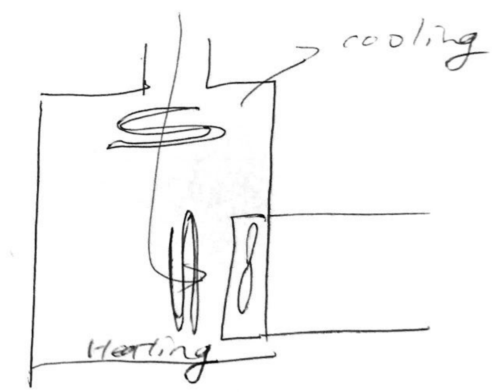


Figure 3. Integrated Heating Elements

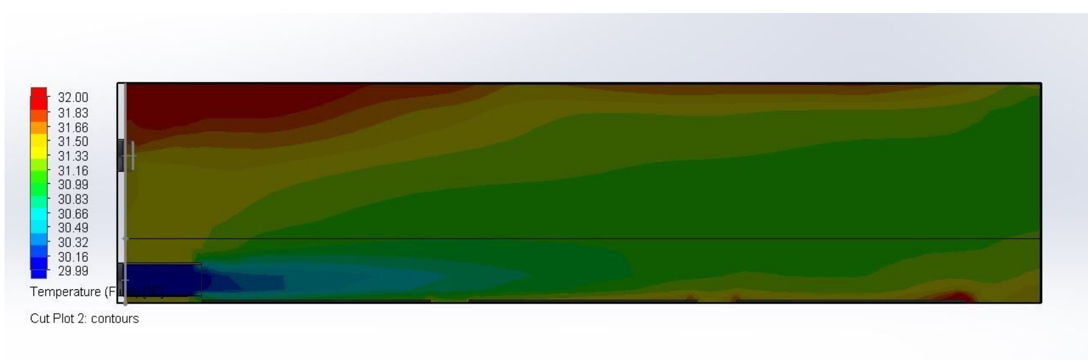


Figure 4. Internal temperature of Concept Heat Pump with Heaters on the ground.

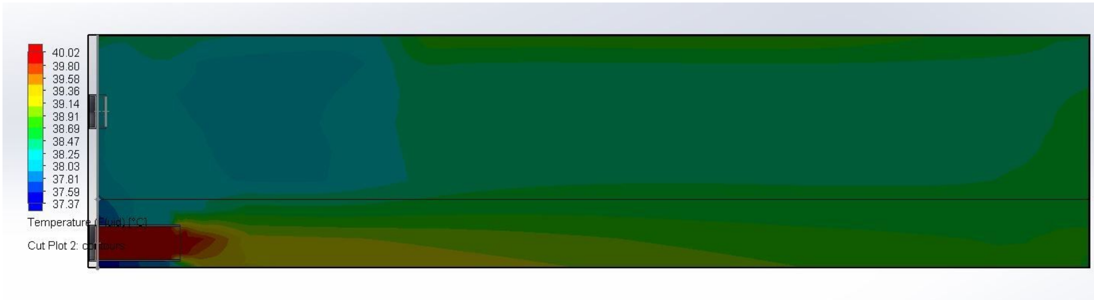
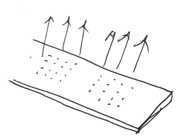


Figure 5. Internal temperature of Concept Heat Pump with Heaters integrated into the air blower.

Adapting to this change, some inlet ducting systems were ideated to help achieve the expected effect.

Ideas	Description
Flat inlet duct 	It was expected to create a wide coverage by this form of duct.
Rounded inlet duct 	The smooth transition of this ducting system was expected to provide three steady vertical airflows

The effect of these two inlet ducting systems were simulated (Fig. 6 & 7) with three even chimneys at the top of the openings. And the difference was significant, therefore the rounded duct was chosen.

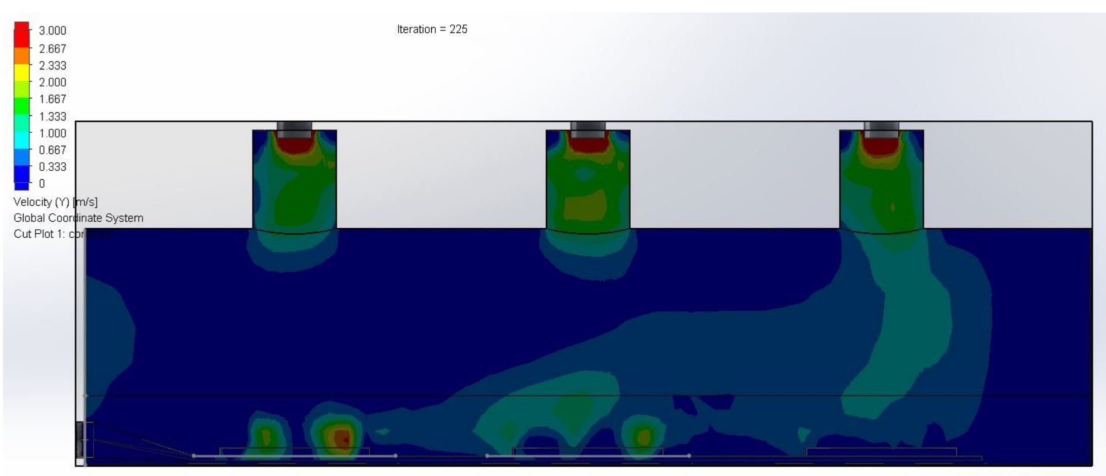


Figure 6. Velocity Performance of the Vertical airflow (Flat Duct).

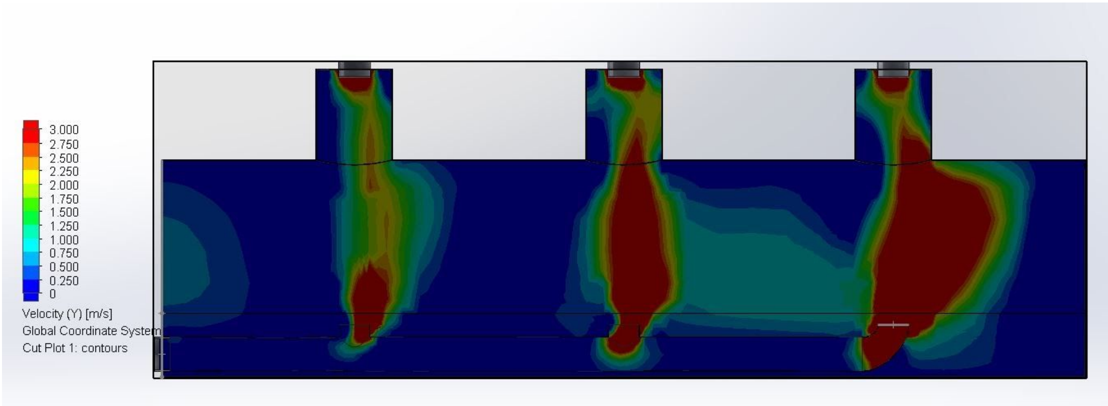


Figure 7. Velocity Performance of the Vertical airflow with Even Chimney Heights (Rounded Duct).

In order to improve the distribution (Fig. 7), the heights of the chimneys were adjusted (Fig. 8). However, the difference was not observed. Therefore, even one was chosen.

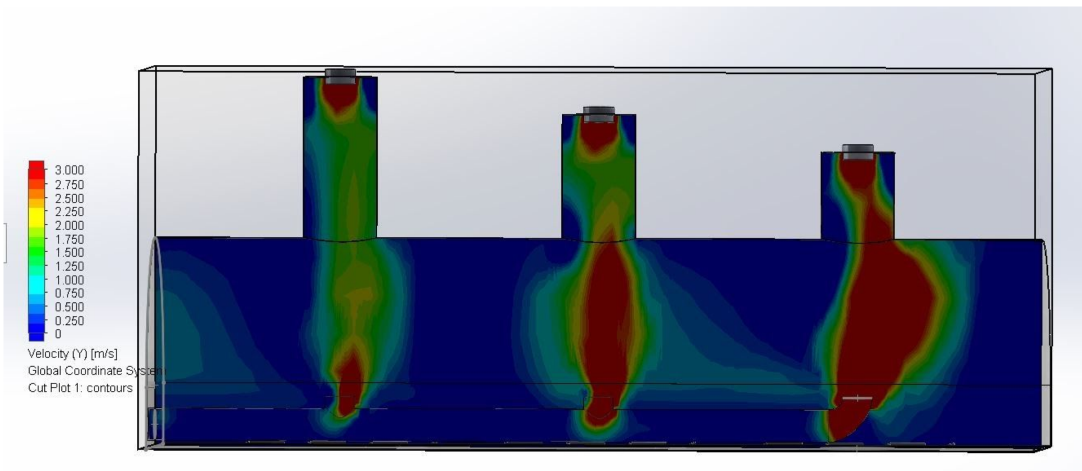


Figure 8. Velocity Performance of the Vertical airflow with Uneven Chimney Heights (Rounded Duct).

In the end, the wind-driven exhaust fan was added to the design with even chimneys at higher positions (Fig. 9) and lower positions (Fig. 10). The effect of lower fans were observed to be better at bridging the vertical velocity. In other words, the reach of the red part was increased by lower fans.

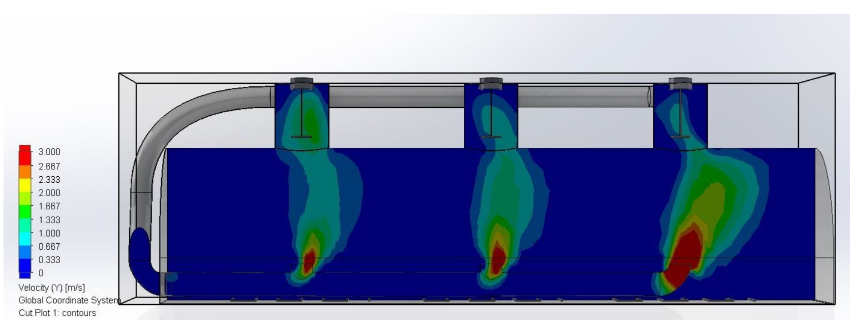


Figure 9. Velocity Performance of the Vertical airflow with Higher Exhaust Fans (Rounded Duct).

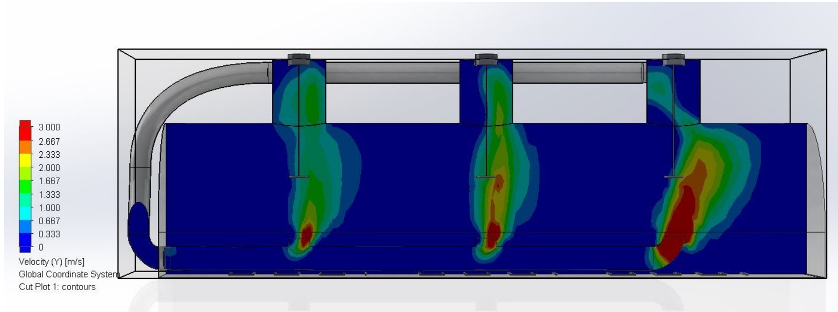
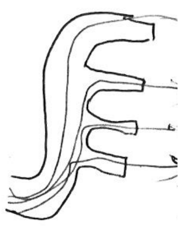
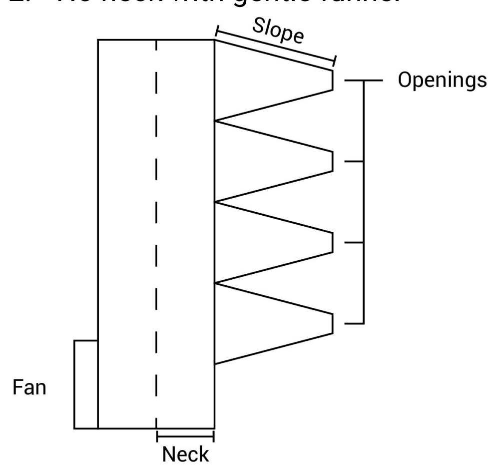


Figure 10. Velocity Performance of the Vertical airflow with Lower Exhaust Fans (Rounded Duct).
*Recirculation ducts were added, therefore the results showed in Fig. 9 & 10 appeared to be different than Fig. 7 & 8.

Horizontal Airflow

To begin with, an air distributor was created to create desired laminar airflow. And the effects of its variation were tested and compared.

Ideas	Description	Variations for Simulation
Laminar air distributor 	It was made to create laminar airflow for each layer	To extend the reach of the airflow and to improve the distribution of each opening, the parameters such as neck, and the slope of the funnel were adjusted. 1. Lengthened neck with steep funnel 2. No neck with gentle funnel 

The effect of these two inlet ducting systems were simulated (Fig. 11 & 12) with a 1-meter chimney at the other side of the greenhouse. The difference was not very significant, but internal airflow of the gentle-slope duct appeared to be more evenly distributed. Therefore, the gentle-slope duct was chosen.

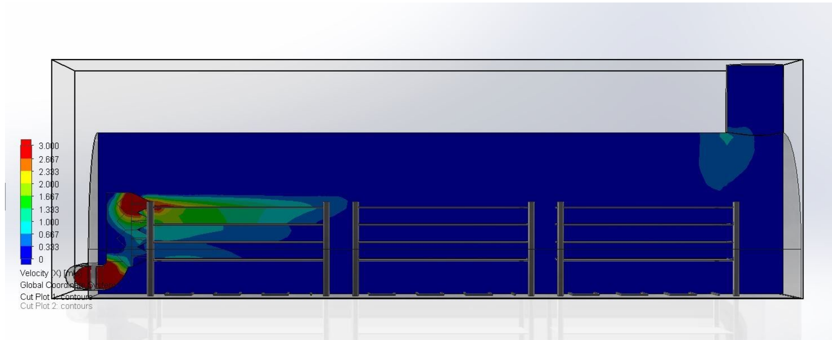


Figure 11. Velocity Performance of the Horizontal airflow with the inlet duct (lengthened neck plus steep funnel).

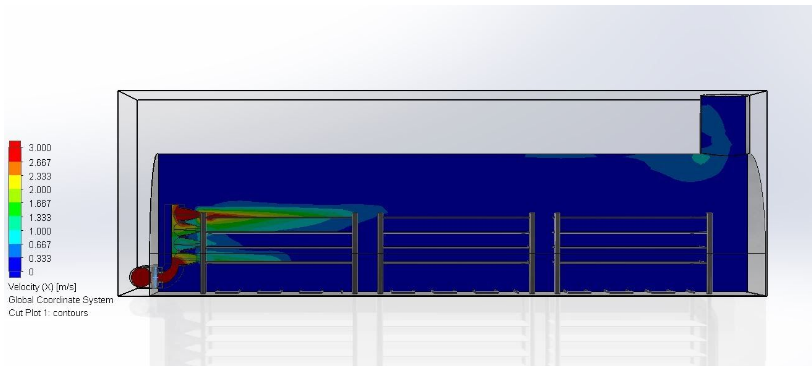


Figure 12. Velocity Performance of the Horizontal airflow with the inlet duct (no neck plus gentle funnel).

Then, the wind-driven exhaust fan was added to the design at a higher position (Fig. 13) and a lower position (Fig. 14). Compared to the situation with no fan, the reaches were observed longer. The performance of these two adjustments looked similar, but the reach of the low-fan one appeared to be slightly longer than that of the higher-fan one. Therefore, the low-fan design was chosen.

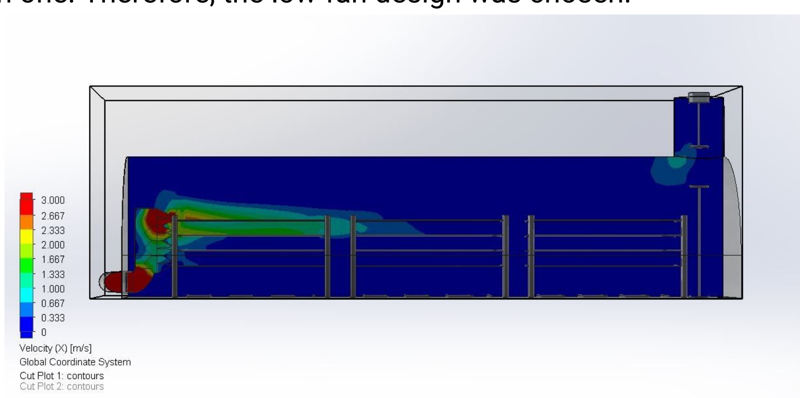


Figure 13. Velocity Performance of the Horizontal airflow with higher exhaust fan.

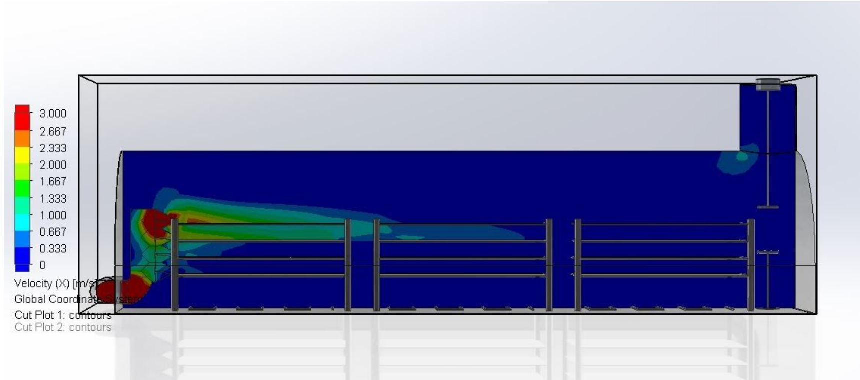


Figure 14. Velocity Performance of the Horizontal airflow with lower exhaust fan.

In order to improve the reach, the height of the chimney was adjusted (Fig. 15). Although a shorter chimney seemed to have a longer reach, however, the longer chimney has more even distribution and higher speed at the bottom (the read area).

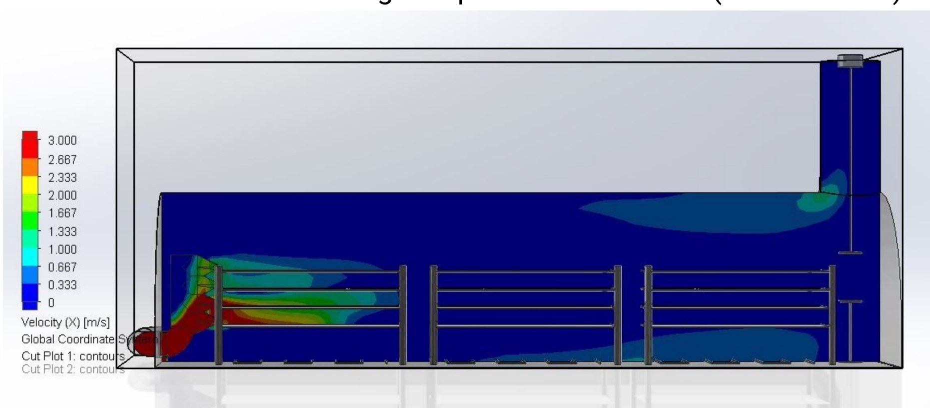


Figure 15. Velocity Performance of the Horizontal airflow with 2-meter chimney.

Additionally, some other fan settings were tested (Fig. 16, 17, and 18). The horizontal fan seemed to have increased the reach, however, it was kept as a reference due to the anticipated implementation difficulties.

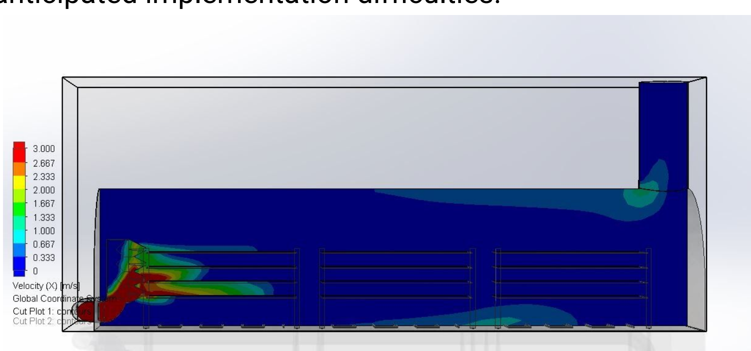


Figure 16. Velocity Performance of the Horizontal airflow with 2-meter chimney (without fan).

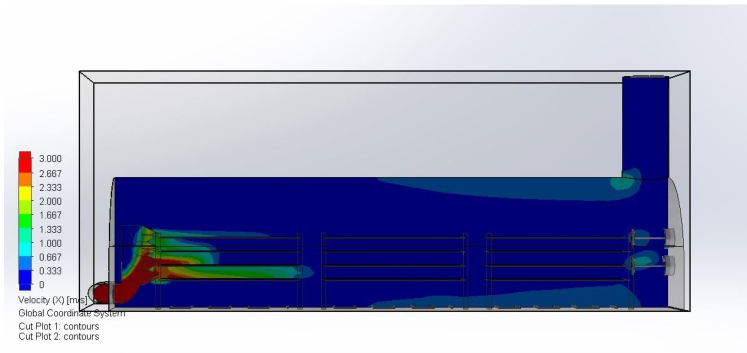


Figure 17. Velocity Performance of the Horizontal airflow with 2-meter chimney (with horizontal fans at the end).

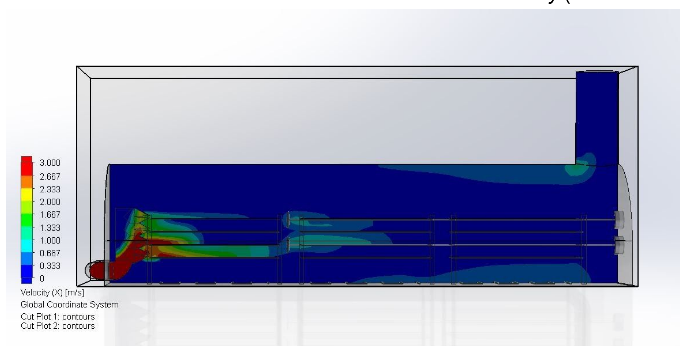


Figure 18. Velocity Performance of the Horizontal airflow with 2-meter chimney (with horizontal fans at the middle).

Expert

According to a heat pump expert in TU Delft, the heat pump system should be heat insulated.

Conclusion

Final Design

For vertical airflow, the final design of this iteration consists of three even chimneys, rounded inlet duct, and three lower exhaust fans. For horizontal-airflow, the design consists of a two-meter chimney, a pair of low exhaust fans and an inlet duct.

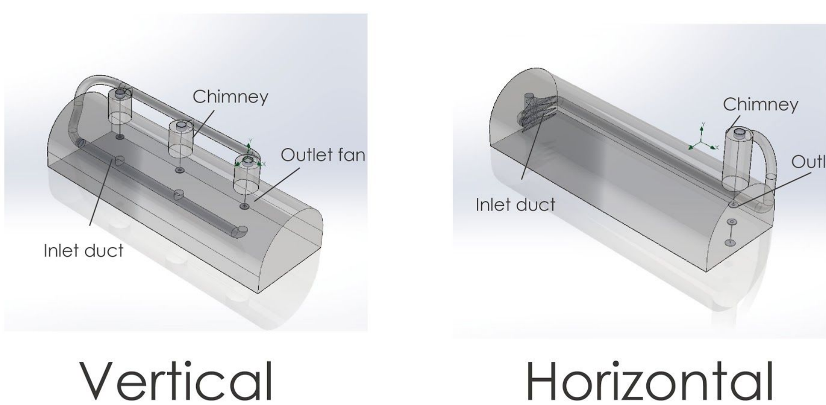


Figure 19. Final designs of the first iteration

As for the heat exchanger and the desiccant layers were integrated into one heating and dehumidification system (Fig. 20).

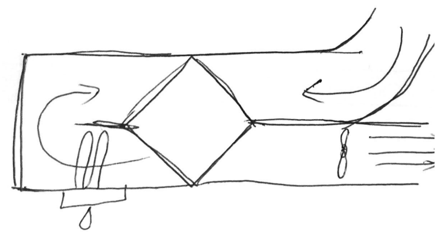


Figure 20. Heating and dehumidification system of the first iteration

Insights

For vertical airflow:

1. The rounded duct seems to be easier for wind redirecting.
2. Uneven chimney heights help air distribution, but the effect is not very significant. While designing, the amount of additional material, the difficulty of construction, and the increase in vertical airflow should be well considered and balanced.
3. Lower fans work as a bridge between inlets and outlets. It brings more air than higher fans.

For horizontal airflow:

1. Funnels with gentle slopes blow air farther than those with steep slopes.
2. Higher chimney balanced out the air from different inlets. The lower inlets have more air than higher inlets, which is the opposite in the lower chimney setup.
3. Lower fan seems to extend the reach of the wind, but not significantly (more experiments are needed).
4. The effect of changing the fan direction is not significant (more experiments are needed).

The developments of horizontal and vertical airflow are not enough to make a choice yet. In the next iteration, the speed loss and difference of the inlets and the heat loss should be addressed to make a decision between these two.

To be improved

1. *Even out the speed difference of each inlet openings*
2. *Reduce speed loss of wind redirection*
3. *Reduce heat loss by adding an insulation layer*

Appendix P Heating and Circulation Iteration 02

Goals

1. Reduce speed loss caused by wind redirection
2. Diminish the speed difference between the openings
3. Increase the coverage of the vertical airflow
4. Reduce heat loss by adding an insulation layer

Parameters

The following table shows the parameters that might affect the heating and circulation performance.

Component	Parameter	Component	Parameter
Heat Pump	Location	Outlet Opening	Location
	Dimension		Dimension
	Specs (power and material)		Specs (form and material of duct)
Greenhouse	Location	Chimney	Location
	Dimension		Dimension
	Specs (material)		Specs (material and amount)
Inlet Fan	Location	Racks	Location
	Dimension		Dimension
	Specs (power, material, and amount)		Specs (Rack Layer Height and amount)
Inlet Opening	Location	Heat Exchanger	Location
	Dimension		Dimension
	Specs(form and material of duct)		Specs (number of layers and material)
Outlet Fan	Location		
	Dimension		
	Specs (power and material)		

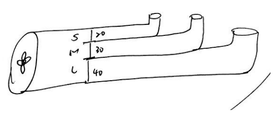
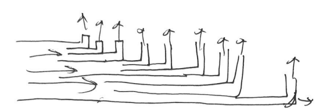
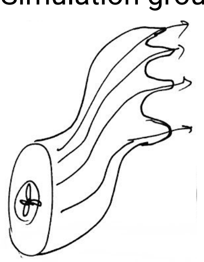
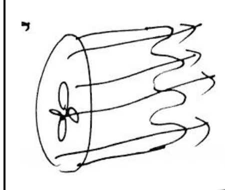
Ideation

The chosen ideas were divided into two groups, concept group, and simulation group. The effects of the simulation group were evaluated by flow simulation.

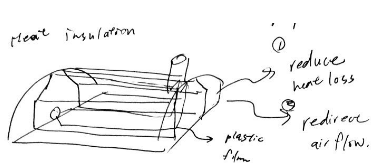
Reduce speed loss caused by wind redirection

The solution is to avoid 90 degree turns and to fillet the corners where wind redirects. This is a general change of the design and was implemented into the design. Therefore, no idea was generated only for this goal.

Diminish the speed difference between the openings & Increase the coverage of the vertical airflow

Chosen Ideas	Description	Variations for simulation (Parameters adjustment)
Separate Ducting System for Vertical Airflow (Simulation group) 	The duct is separated into three. The openings that are closer to the fan has smaller duct diameters in order to balance the air distribution (because the wind tends to find the shortest route to the exit)	1. Increase the opening sizes for wider coverage 2. Increase the width and the number of openings for wider coverage 
Smoother Transition for Horizontal Airflow (Simulation group) 	The smoother transition is made to evenly transfer the air to the openings in order to improve the distribution.	1. Lift the fan to improve the distribution and the velocity 

Reduce heat loss by adding an insulation layer

Chosen Ideas	Description
Side Insulation Layers (Simulation group) 	The insulation layers on the sides are aiming to reduce the heat loss during rainy days.

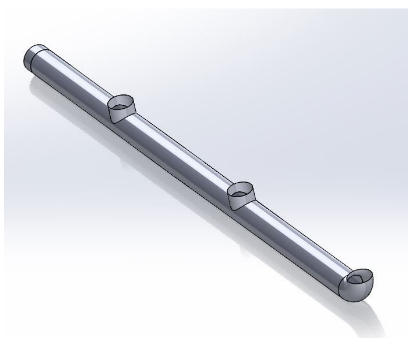
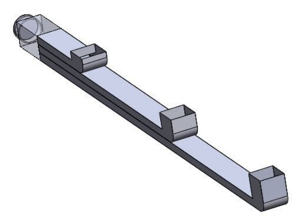
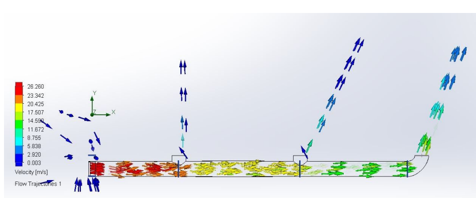
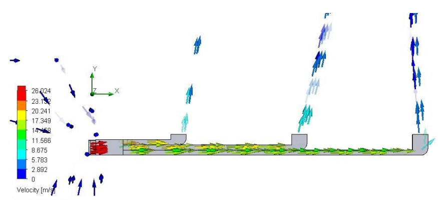
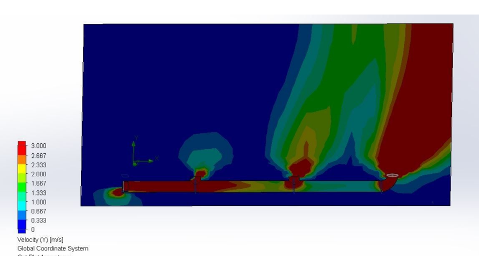
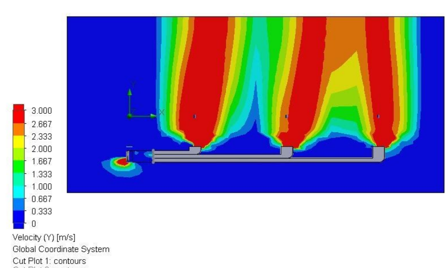
Prototyping

Simplified 3D models of the simulation group were made in Solidworks for airflow study.

Evaluation (Simulation)

Vertical Airflow

To begin with, the separate ducting was made (2 in Table 1). The air distribution is observed to be better than that of the original design (1 in Table 1). Then, the openings were enlarged (3 in Table 1). However, the airflow did not increase its coverage and the velocity even decreased. The same situation happened when the number and the width of the openings were increased (4 in Table 1). Therefore, these two ideas were not adopted.

No.	1	2
Model		
Airflow		
Vertical Air Velocity		

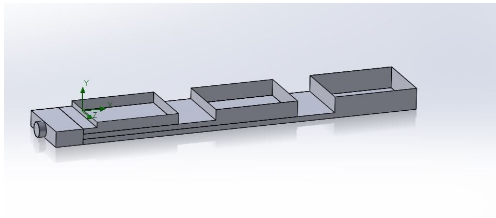
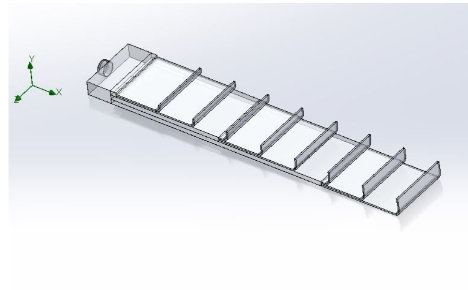
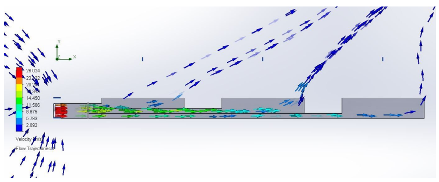
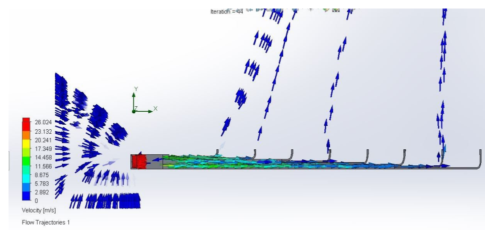
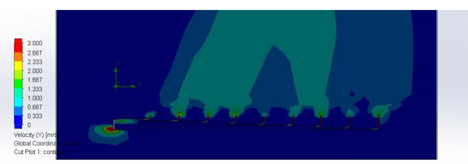
No.	3	4
Model		
Airflow		
Vertical Air Velocity		

Table 1. The process of improving the distribution and coverage of the vertical airflow

Additionally, the effects of the exhaust fan were again studied to validate the findings from the previous iteration. And the result (Table 2) showed that installing the fans at a lower height had the best performance on extending the velocity (the red area).

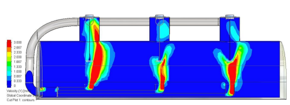
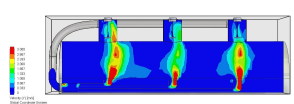
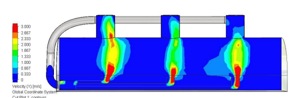
	1 low fan	2 high fan	3 no fan
Vertical Air Velocity			

Table 2. The comparison of the air velocity of different fan settings

In the end, the insulation layers were added to the design. The internal temperature appeared to be more even, and the overall temperature appeared to be higher (Table 3) after adding the layers.

	Without Insulation Layers	With Insulation Layers

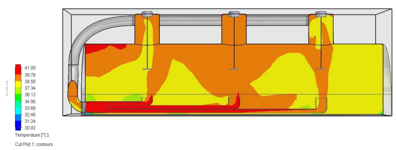
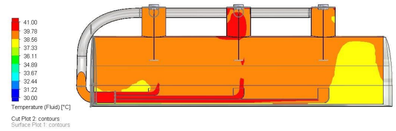
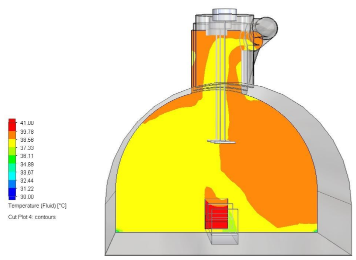
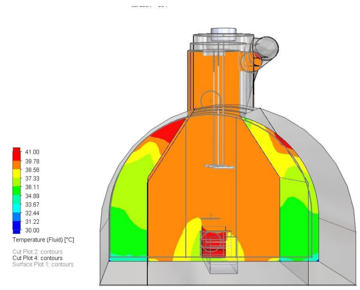
Internal Temperature (Side view)		
Internal Temperature (Front view)		

Table 3. The temperature comparison with and without the insulation layers.

Horizontal Airflow

The inlet ducts with smoother transitions (2 in Table 4) and with lifted fan (3 in Table 4) were simulated and compared. The design with a lifted fan was observed to have the best reach and distribution.

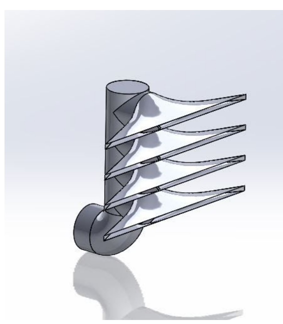
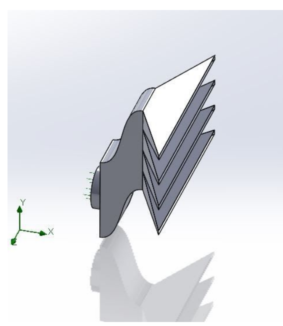
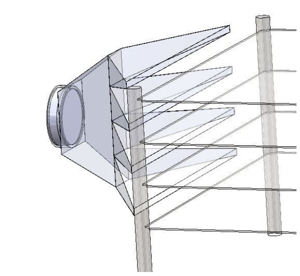
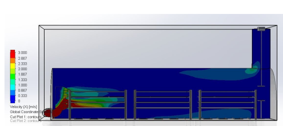
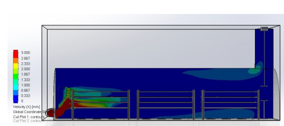
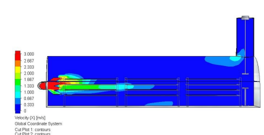
	1	2	3
Models			
Horizontal Air Velocity			

Table 4. The comparison of three different inlet ducts.

Due to simulation difficulties, the heating element was disabled, therefore, the temperature on the drying chamber was generally lower than that of the insulation chambers. However, the general internal temperature appeared to be higher than without insulation layers (Table 5).

One thing worth mentioning is that while testing the ducts, it was observed that the airflow was curved. The insulation layers redirected the airflow, thus had a better reach.

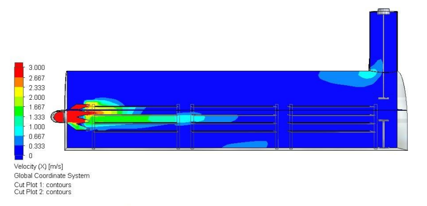
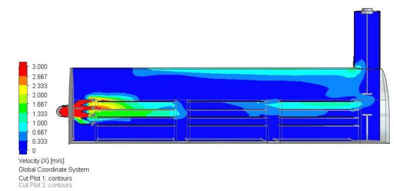
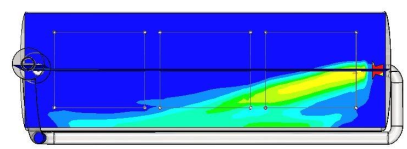
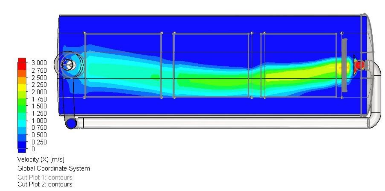
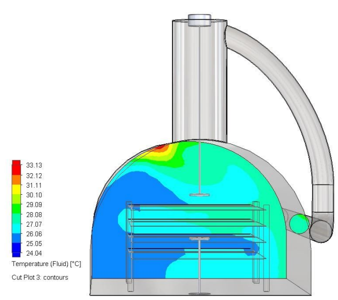
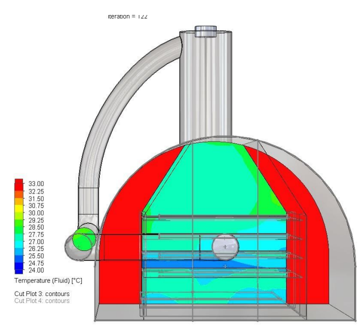
	Without Insulation Layers	With Insulation Layers
X-direction Air Velocity (Side View)		
X-direction Air Velocity (Top View)		
Internal Temperature (Front View)		

Table 5. The temperature and airflow comparison with and without the insulation layers.

Expert

The result was discussed with a greenhouse expert, and the following suggestions were given to improve the performance,

1. Horizontal: add fans in between to recirculate the air
2. Vertical: Try air distribution hose

Stakeholder

1. Add guiding sheets to direct the airflow (it may also help catch dripping water)

Conclusion

Final Design

For vertical airflow, the final design of this iteration consists of three even chimneys, an inlet duct with three branches (Fig. 2), three lower exhaust fans, and insulation layers on the sides. For horizontal-airflow, the design consists of a two-meter chimney, a pair of low exhaust fans, a lifted inlet duct(Fig. 3), and insulation layers on the sides.

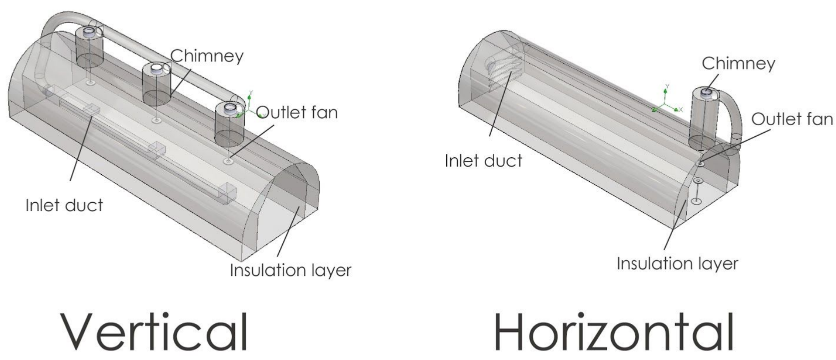


Figure 1. Final Designs for Vertical and Horizontal Airflow

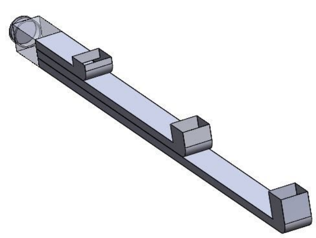


Figure 2. Inlet Duct for Vertical Airflow

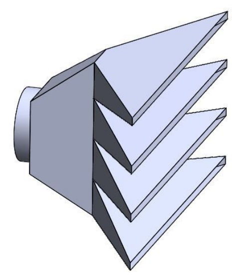


Figure 3. Inlet Duct for Horizontal Airflow

To be improved

Vertical:

1. Increase the inlet coverage

Horizontal:

1. Increase the width of the airflow

General:

1. Reduce speed loss
2. Improve the slightly uneven air distribution of each opening

Appendix Q Heating and Circulation Iteration 03

Goals

1. Vertical: Increase the airflow coverage
2. Horizontal: Increase the width of the airflow
3. Reduce the speed loss
4. Improve the slightly uneven air distribution of each opening

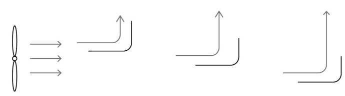
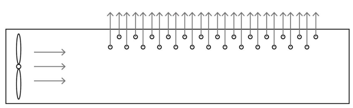
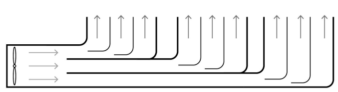
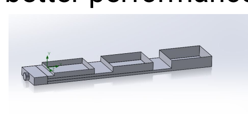
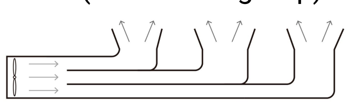
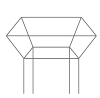
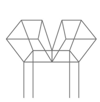
Parameters

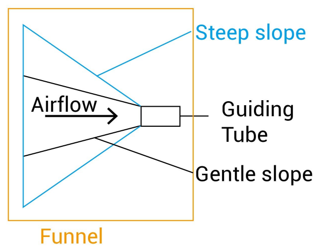
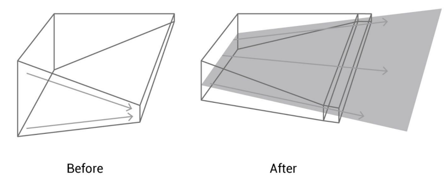
The following table shows the parameters that might affect the heating and circulation performance.

Component	Parameter	Component	Parameter
Heat Pump	Location	Outlet Opening	Location
	Dimension		Dimension
	Specs (power and material)		Specs (form and material of duct)
Greenhouse	Location	Chimney	Location
	Dimension		Dimension
	Specs (material)		Specs (material and amount)
Inlet Fan	Location	Racks	Location
	Dimension		Dimension
	Specs (power, material and amount)		Specs (Rack Layer Height and amount)
Inlet Opening	Location	Heat Exchanger	Location
	Dimension		Dimension
	Specs(form and material of duct)		Specs (number of layers and material)
Outlet Fan	Location		
	Dimension		
	Specs (power and material)		

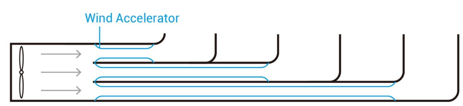
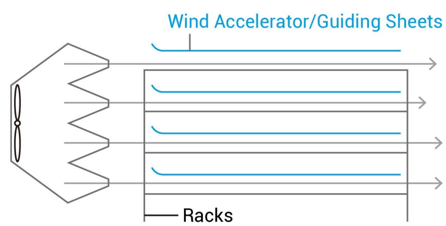
Ideation

Increase the airflow coverage (vertical)/Increase the width of the airflow(Horizontal)

Chosen Ideas	Description	Note
Guiding Sheets for Vertical Airflow (Simulation group) 	Using several wide sheets to guide the airflow upward to create a wider coverage.	New idea from stakeholders
Air Distribution Hose for Vertical Airflow (Simulation group) 	This idea aimed to create vertical airflow by releasing air from the top holes of the hose.	New idea from the greenhouse expert
Wide Openings with Guiding Sheets for Vertical Airflow (Simulation group) 	The model with wide openings from the second iteration did not have a good result. In this iteration, guiding sheets were added to the model for a better performance. 	
Diffusers for Vertical Airflow (Simulation group)  	A diffuser is added to the end of each opening of the last iteration's final design.	
V-shaped diffusers for Vertical Airflow (Simulation group) 	A V-shaped diffuser is added to the end of each opening of the last iteration's final design.	Advice from a wind expert

Gentle slopes and guiding tubes for Horizontal Airflow (Simulation group)  	The slopes of the funnels were adjusted to be less steep and some guiding tubes were added at the tips of the funnels. This was expected to increase the width by reducing the vertical forces (See figure below.  	

Reduce the speed loss

Chosen Ideas	Description
Wind Accelerator for Vertical Airflow (Simulation group)  	The narrowed wind channels were expected to increase the wind speed.
Wind Accelerator (guiding sheet) for Horizontal Airflow (Simulation group)  	The guiding sheets were expected to increase the wind speed.

Most of the ideas for this improvement were general adjustments, i.e., adjustments that can be applied to the former designs (see the table below). These adjustments were added to the design and then simulated.

Adjustments	Description
Extending Exit Ducts	According to the advice from a wind expert, extending the duct after the 90 degree turns may help to stabilize the airflow, which may also help to improve the reach of the airflow to a desired direction.

Opening sizes	According to the advice from a wind expert, the bigger the area of the opening is, the lower the air velocity it will get. Therefore, the area of the openings should not be much bigger than the area of the fan in order to keep the velocity.

Improve the slightly uneven air distribution of each opening

Adjustments	Description
Opening sizes	According to the advice from a wind expert, varying the opening size may affect the amount of air coming out from that opening.

Prototyping

Simplified 3D models of the simulation group were made in Solidworks for airflow study.

Evaluation (Simulation)

In this iteration, all ideas were tested separately and evaluated by their air distribution, velocity, and coverage. The weights of the evaluation criteria depend on the purpose of the design, i.e., if the idea was generated to increase the coverage, then the coverage would have a heavier weight than other two criteria. At the end, all chosen ideas were combined as the outcome of this iteration.

Vertical Airflow

To begin with, the new ideas to increase the coverage were simulated and compared first (Table 1). The lengths of the guiding sheets were adjusted during the simulation to get a better result (Fig. 1). However, the coverage, distribution, and velocity all appeared to be worse than the original design.

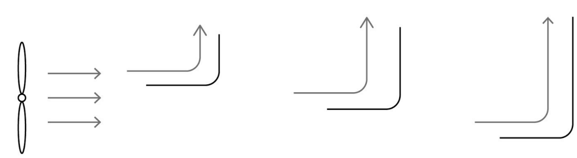
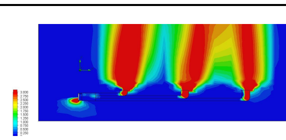
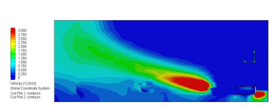


Figure 1. Extended length of the guiding sheet

	Original	Guiding sheet	Air distribution hose
Vertical Air Velocity		 Short	

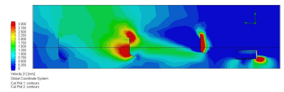
		 Long	

Table 1. The simulation results of the new ideas.

Then, the idea of adding guiding sheets in wide-opening ducts was tested (Table 2). Though the coverage seemed to be improved, it was still insufficient compared to the original design.

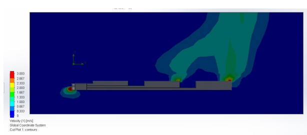
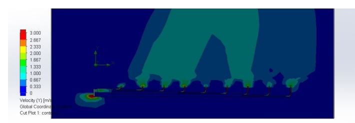
	Without guiding sheet	With guiding sheet
Vertical Air Velocity		

Table 2. The simulation result of the wide-opening ducts with guiding sheets.

A diffuser and a V shaped duct were simulated (Table 3). And the diffuser had the widest area among them.

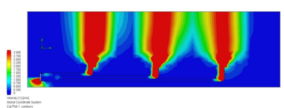
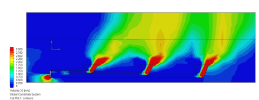
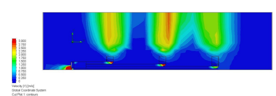
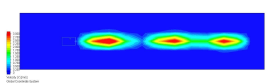
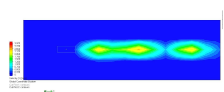
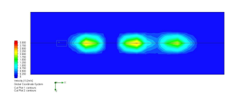
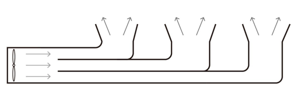
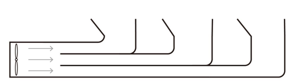
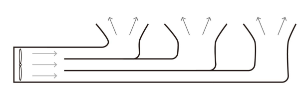
	Original	Diffuser	V-shape
Vertical Air Velocity (Side View)			
Vertical Air Velocity (Top View)			

*Table 3. The simulation results of different diffusers for vertical airflow (*the values of the area do not represent the actual size of the coverage. It is unitless, and only for comparison)*

In order to improve the coverage, some other adjustments on the diffuser were experimented (Table 4). And the one with narrow necks and brims had the best coverage among them.

	Original diffuser	Shifted	Fillet
Graphic of the Duct			

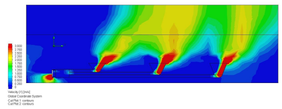
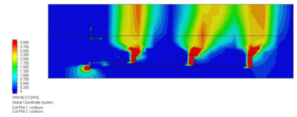
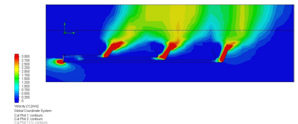
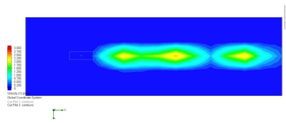
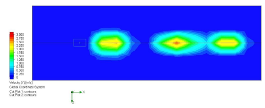
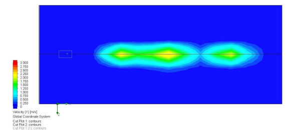
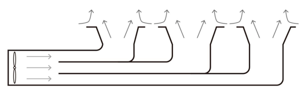
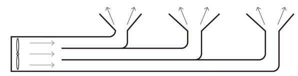
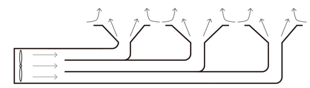
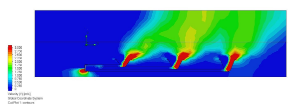
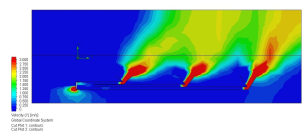
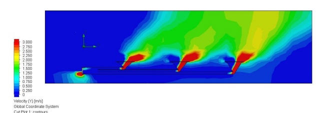
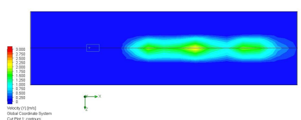
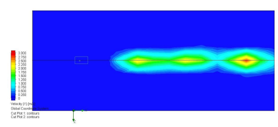
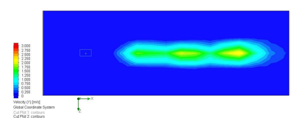
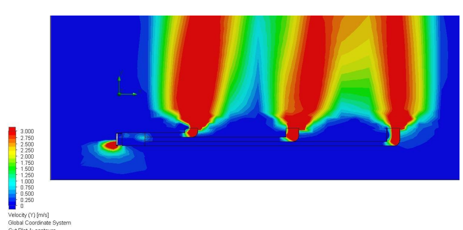
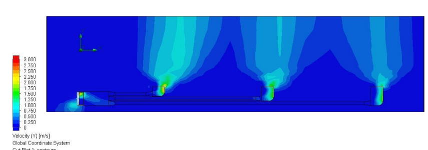
Vertical Air Velocity (Side View)			
Vertical Air Velocity (Top View)			
Coverage Rank	5	6	4
	Original with brim	Narrow Neck	Narrow Neck with brim
Graphic of the Duct			
Vertical Air Velocity (Side View)			
Vertical Air Velocity (Top View)			
Coverage Rank	3	2	1

Table 4. The simulation results of different diffuser settings for vertical airflow

For speed loss reduction, the wind accelerator was tested (Table 5). The result of the wind accelerator (narrowed ducts) showed that the air velocity was less than that of the original.

	Original	Wind Accelerator
Vertical Air Velocity		

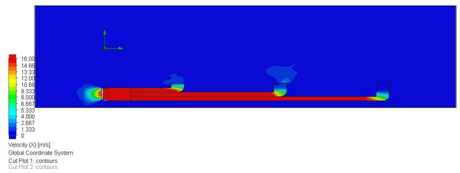
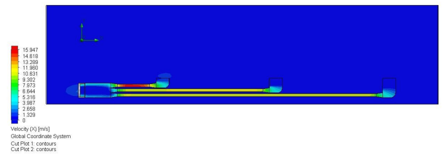
X-direction Air Velocity		

Table 5. The simulation result of the wind accelerator for vertical airflow.

Next, some variations of the exit duct were tested (Table 6) to improve the velocity. The funnel-shaped duct seemed to have lower overall velocity. The velocity of design with long extensions was similar to that of the original design. But the airflow direction is more straight than that of the original design.

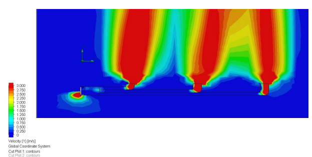
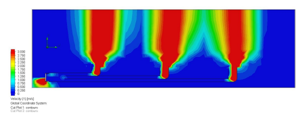
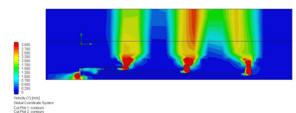
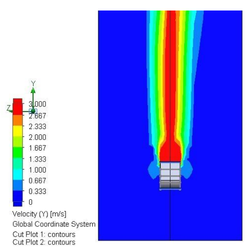
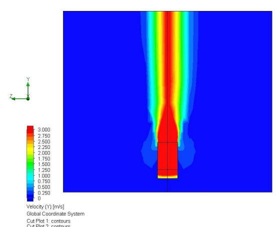
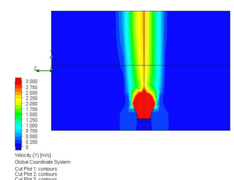
	Original	Long extensions	Funnel shaped duct (width>length)
Vertical Air Velocity (Side View)			
Vertical Air Velocity (Front View)			

Table 6. The simulation results of different exit duct settings for vertical airflow

As for the distribution, the uneven distribution was not observed during the simulation, thus, it was not simulated.

Then, the chosen ideas were combined into one design (Table 7) and compared to the original design. Although the ideas to decrease speed loss did not work as expected, it was still added in since it stabilized the airflow. The speed of the final design appeared to be less than the original design (less red area). However, it was accepted because speed reduction happens when the coverage increases.

	Original	Increase width	Stabilization	Combination
		Diffuser with Narrow Necks and brims	Long extension	Diffuser with Narrow-and-Long Necks and brims

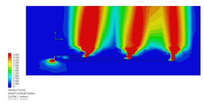
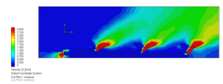
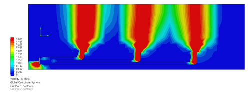
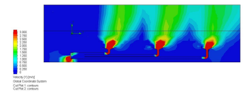
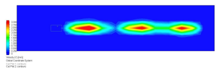
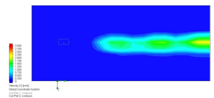
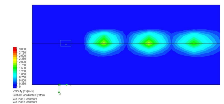
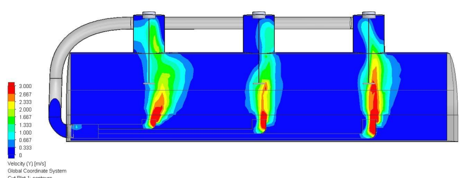
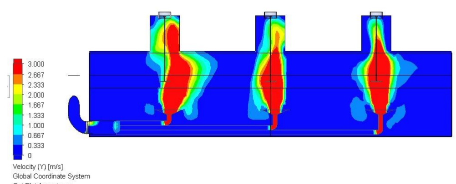
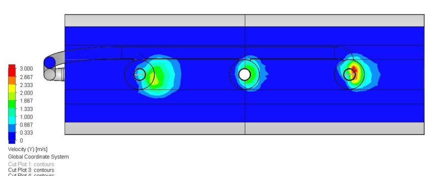
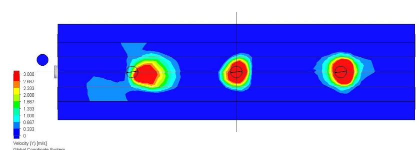
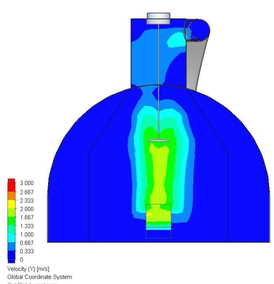
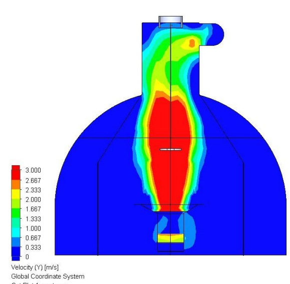
Vertical velocity (Side View)				
Vertical velocity (Top View)				
Covered Area*	47166	79687		55171 (17%wider)
Velocity*	0.318			0.320 (0.6%faster)

*Table 7. Idea Combination for Vertical Airflow (*the values of the covered area and velocity do not represent the actual number. It is unitless, and only for comparison)*

At the end, the design was combined into the greenhouse and simulated (Table 8). The chimney and recirculation system seemed to be helping the velocity and coverage performance of the new design. The coverage increased around 40% and the velocity increased around 70%.

	Original	New
Vertical velocity (Side View)		
Vertical velocity (Top View)		
Vertical velocity (Front View)		

Covered Area*	25121	35124 (39.8% Wider)
Velocity*	0.1206	0.2047 (69.7% Faster)

*Table 7. Final Comparison for Vertical Airflow (*the values of the covered area and velocity do not represent the actual number. It is unitless, and only for comparison)*

Horizontal Airflow

To increase the coverage the slopes of the funnels were adjusted and some other parameters were also adjusted (Table 8). The gentle slope seemed to have the best coverage among the adjustments.

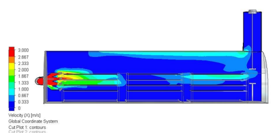
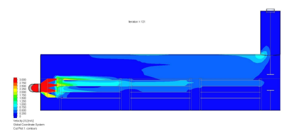
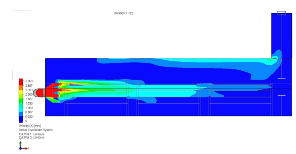
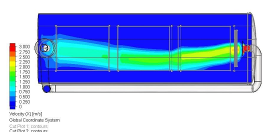
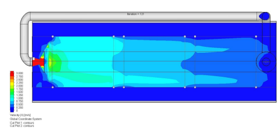
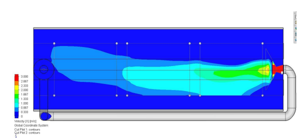
	Original	Gentle slope with Guiding tubes	Shorten openings
X-direction Air Velocity (Side View)			
X-direction Air Velocity (Top View)			

Table 8. Coverage comparison of different duct settings for horizontal airflow

To increase the speed and the reach of the airflow, wind accelerators(guiding sheets) and recirculation fans were simulated (Table 9). Adding a recirculation fan appeared to have a better result, but considering its extra energy consumption, it was decided to be a reference for future development. Therefore, the long wind accelerator was chosen since it had the best performance in increasing the speed and the reach.

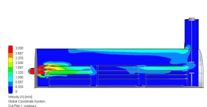
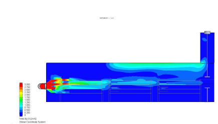
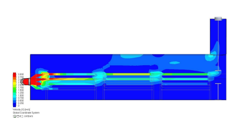
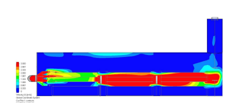
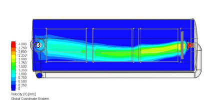
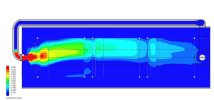
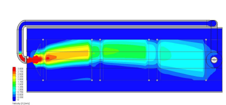
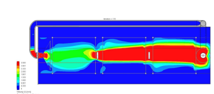
	Original	Short Wind accelerator/guiding sheet	Long Wind accelerator/guiding sheet	Recirculation Fan
X-direction Air Velocity (Side View)				
X-direction Air Velocity (Top View)				

Table 9. Speed and reach comparison of different settings for horizontal airflow

The air distribution for horizontal design was uneven. In order to address this situation, several parameters (Fig. 2) of the openings were adjusted and simulated (Table 10). The design with narrow neck and uneven joint sizes appeared to have the most even distribution among all of them.

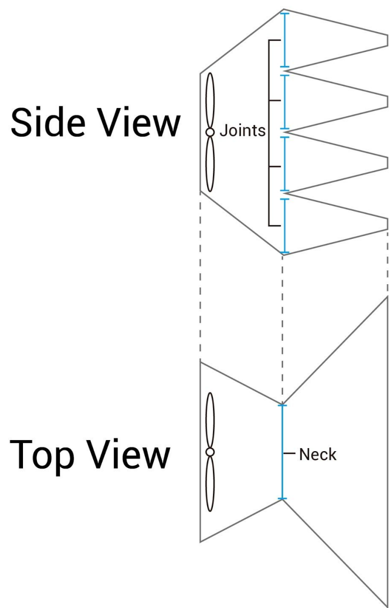
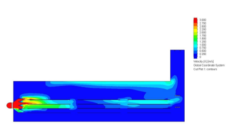
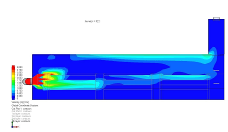
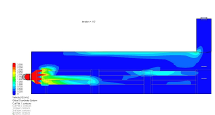
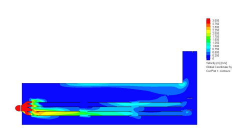
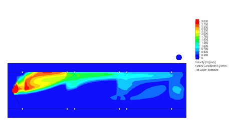
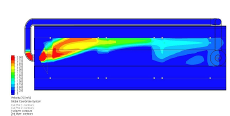
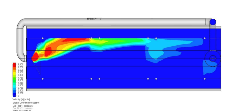
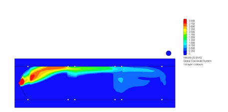
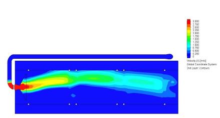
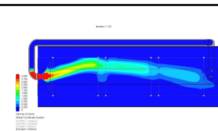
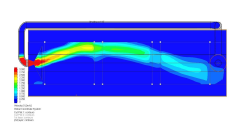
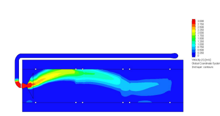


Figure 2. Side View and Top View of the Inlet Duct for Horizontal Airflow

	Original	Uneven Joint Sizes	Narrow Neck	Narrow Neck with Uneven Joint Sizes
X-direction Air Velocity (Side View)				
X-direction Air Velocity (1st Layer Top View)				
X-direction Air Velocity (2nd Layer Top View)				

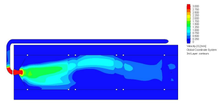
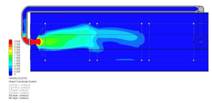
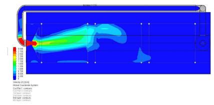
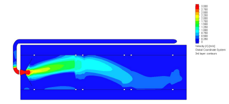
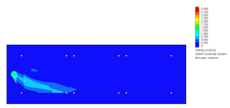
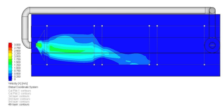
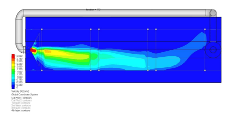
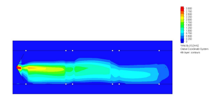
X-direction Air Velocity (3rd Layer Top View)				
X-direction Air Velocity (4th Layer Top View)				

Table 10. Air distribution comparison of different settings for horizontal airflow

In the end, the chosen ideas were combined into one design and simulated (Table 11). Compared to the original design (Table 12), the coverage increased around 52% and the average velocity increased around 93%.

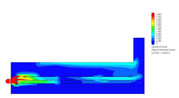
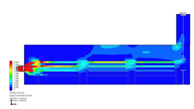
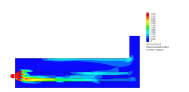
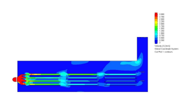
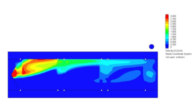
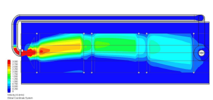
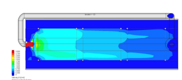
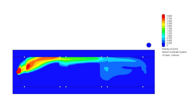
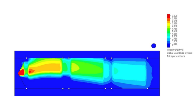
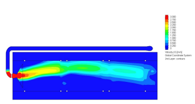
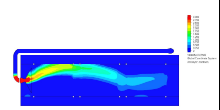
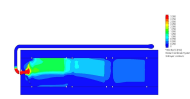
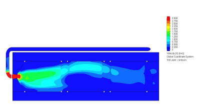
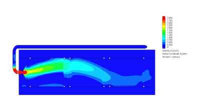
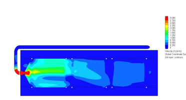
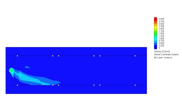
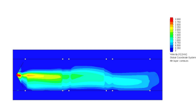
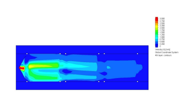
	Original	Improve speed and reach	Increase width	Improve distribution	Combination
		Long Wind Accelerator (guiding sheet)	Gentle slope	Narrow Neck with Uneven Joint Sizes	
X-direction Air Velocity (Side View)					
X-direction Air Velocity (1st Layer Top View)					
X-direction Air Velocity (2nd Layer Top View)					
X-direction Air Velocity (3rd Layer Top View)					
X-direction Air Velocity (4th Layer Top View)					

Table 11. Idea Combination for Horizontal Airflow

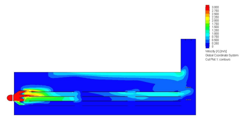
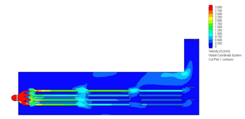
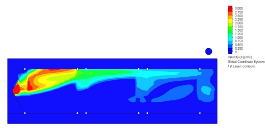
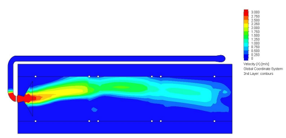
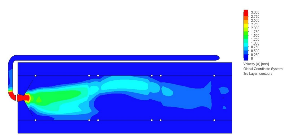
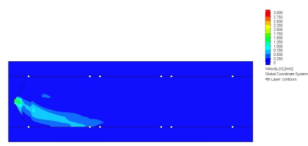
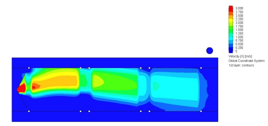
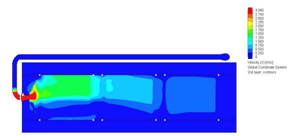
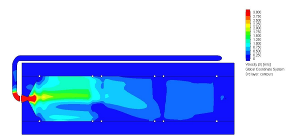
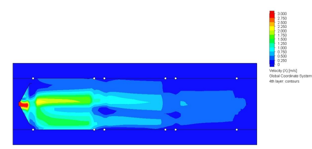
	Original	New
X-direction Air Velocity (Side View)		
X-direction Air Velocity (All Layers Top View)	   	   
Covered Area*	138650	210446 (increased 51.8%)
Velocity*	0.3432	0.6608 (increased 92.6%)

*Table 12. Final Comparison for Horizontal Airflow (*the values of the covered area and velocity do not represent the actual number. It is unitless, and only for comparison)*

Conclusion

Final Design

For vertical airflow, the final design of this iteration consists of three even chimneys, an inlet duct with diffusers and brims at the openings(Fig. 3), three lower exhaust fans, and insulation layers on the sides. For horizontal-airflow, the design consists of a two-meter chimney, a pair of low exhaust fans, a lifted inlet duct(Fig. 4), guiding sheets on the nets and insulation layers on the sides.

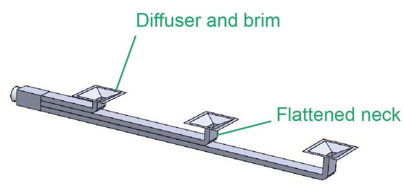


Figure 3. Inlet Duct for Vertical Airflow

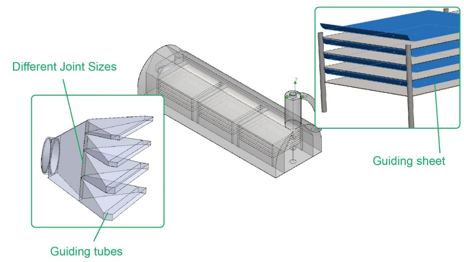


Figure 4. Inlet Ductand Guiding Sheets for Horizontal Airflow

To be improved

1. Air distribution and air velocity of the design for horizontal airflow

Appendix R-1 Procedure of Drying Test

Objective:

1. To validate whether the drying rates of the layers are equivalent to each other
2. To determine whether turning can be omitted

Assumptions:

1. The humidity and temperature of the testing environment do not affect the relative drying rate of the nets.
2. The material of the net does not affect the relative drying rate.
3. Different sewing techniques do not affect the drying process.
4. Assume that the drying process

Research Questions:

1. Are the drying rates of the layers equivalent to each other?
2. Can fish be dried completely without turning?

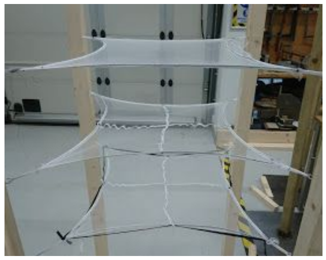
Method:

Setup:

Frame:

Outer Dimensions - 62 cm x 62cm x 210 cm (W/L/H)
Inner Dimensions - 57 cm x 57cm x 200 cm (W/L/H)
Hooks heights: 110cm/ 130cm / 150cm
Cover: PE film

Nets:



Amount: 3
Mesh size: 2 mm
Thickness: less than 0.1 mm
Material: polyester
Dimension: 50 cm x 50cm (square net excluding the hanging loops)

Fan:

Power: 98/110/125 Watt (adjustable)
Diameter: 500 mm
Volume flow rate: 6600 M^3/h

Fish:

Quantity: 12
Dimension: length: 10-12 cm / belly width: ~1cm
Weight:

1- 16.9g	2- 15.5g	3- 10.8g	4- 11.1g
5- 11.6g	6- 16.2g	7- 12.7g	8- 10.2g
9- 14.4g	10- 11.9g	11- 15.7g	12- 14.5g

Initial inside temperature and humidity:
Temperature:27.0 °C Relative Humidity: 56%

External factors:
Weather - Sunny (nearly no cloud)/ 26-28 °C/ Humidity ~60%

Procedure:

1. The setup was placed in the balcony where sunlight was available all the time on the south side of the setup.

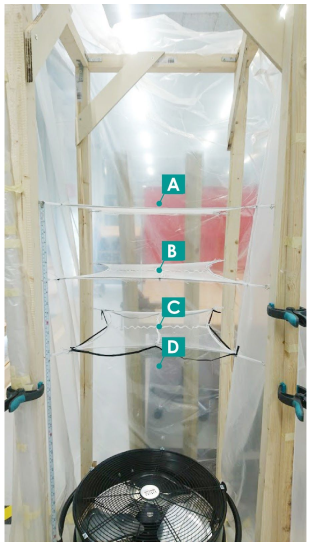
2. The weights of the fish were measured separately.

3. One fish was put at each corner of each net. In total, twelve fish was placed in the setup.

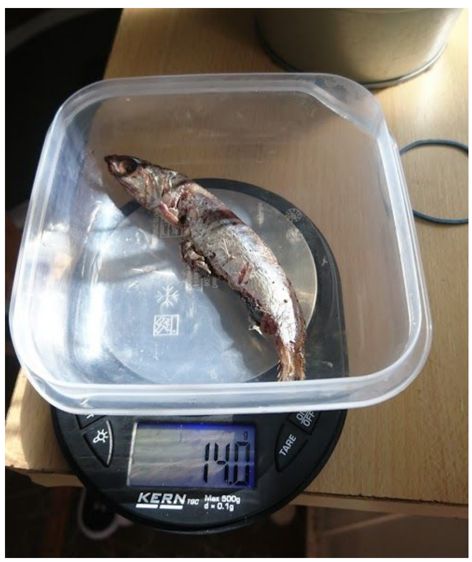
4. The PE film was wrapped around the frame. Some openings were made at the bottom of all sides to allow air entry. The top of the setup was not covered by the film.

5. The fan was turned to the first gear.

6. The initial inside and outside temperatures, the temperature of each layer (at A, B, C, and D), and inside humidity were measured at the beginning of the drying process.




7. The factors in step 6 were measured every hour after the start. Then the fish was taken out one by one to measure the weight loss (the fish was placed back to the original spot without flipping the sides). And the air velocity of each layer was measured every hour in the first three hours.



8. After 5 hours, the drying test was terminated due to the weather condition.
9. The drynesses of the fish on both sides were observed.

10. The dry matters of the fish were measured by drying the fish in an oven at 60 °C for 2 more hours

Apparatus:

1. The humidity and inside temperature were measured by a digital indoor thermometer (brand: Alecto; model: WS-75)
2. The temperature and air velocity were measured by an anemometer (brand: testo; model: 425)
3. The weights were measured by a digital scale (brand: Kern; model: TGC 500-1)
4. The data was logged manually

End of the research:

When the weights stop dropping or until the weather condition is not sufficient to conduct the test.

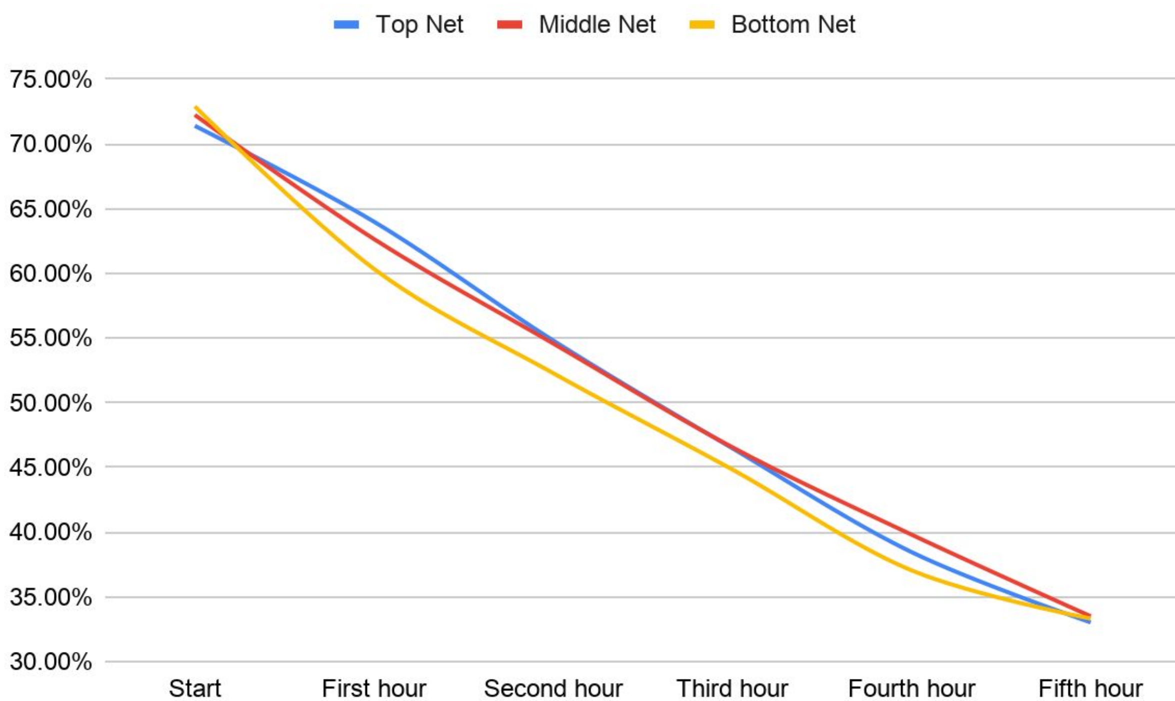
Limitation:

1. The sunlight might influence the reading of the inside temperature.
2. The fish for the test was bigger than dagaa; thus, the drying rate might be different.
3. The air swirl blown by the axial fan might have an influence on the result of the test.

Result and Discussion:

Drying Rates:

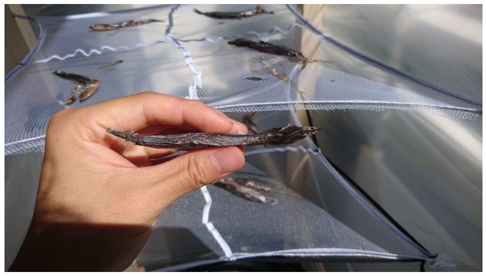
Generally speaking, higher positions have higher temperatures and lower air velocities compared to the lower positions (see the raw data). The following figure shows the average weight loss (in percentage) of each layer in relation to drying time. The fish on the bottom layer dries faster than those of the top layer; however, in the fifth hour, the drying difference was only around 2%. According to Project Dagaa, due to the temperature difference between layers, the top layer dried faster than the bottom layer when drying with racks without forced ventilation; Compared to the result of this test, an upward airflow may reverse the order of faster drying layer and slower drying layer. The drying rates were expected to be more even between different layers if the temperature difference were larger; However, a further test should be done to investigate this assumption.

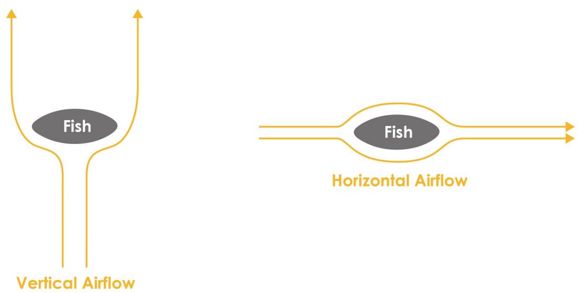


Side turning:

Although the drying test was terminated before the fish were dried, however, the accomplishment rates of the drying results were above 91%*. Therefore, it was expected to be fully dried with a longer drying time. In this point of view, the turning operation is not needed.

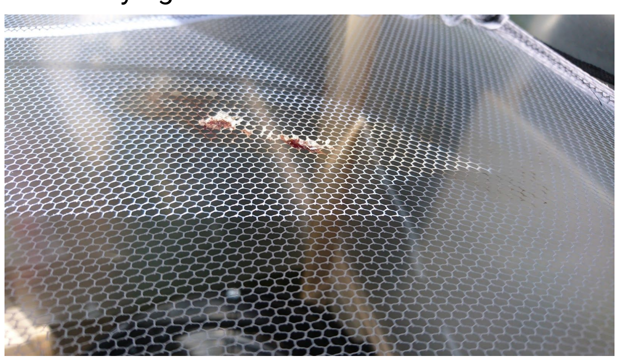
However, through observation, the sides facing upward appeared to have more moisture content left than the sides facing downward. The reason might be that there was no direct sunlight irradiating on the fish, but there was constant airflow blowing from the bottom; therefore, the bottom side dried faster than the top side. In this perspective, horizontal airflows may dry both sides more evenly; however, a further test is needed.



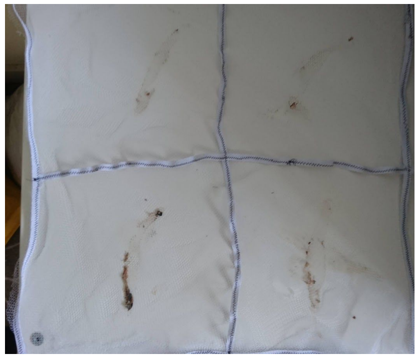


Furthermore, when the tester was removing the fish for weighing at the first hour, some of the fish was stuck onto the net; and pieces of flesh or skin were left on the net afterward. Nonetheless, the sticking situation only happened at the first removal.
*calculated by dividing the actual weight loss by the target weight loss.

In the pilot test, it was found that the fish skin was stuck on the net; therefore, the fish number eleven was left untouched until the third hour to observe whether the sticking situation will be solved over time. However, it was still stuck on the net after three hours of drying.



In addition, it was observed that the sticking issue was more severe in lower layers than the top layer. Compared to the data, the sticking issue seems to have a negative correlation with the drying rate of the first hour and a positive correlation with the temperature. However, the data was not enough to distinguish it; therefore, another test is recommended to identify the correlation.

Other insights:

During the test, the fish attracted many flies, mostly at the top layer. The airflow at the top layer does not seem to affect the flies. According to the article (https://www.pctonline.com/article/pct0613-fly-management-air-currents/), certainly, airflow can repel flies. Comparing this finding to the result, applying fast airflow, around 2.65 to 3.78 m/s may have an effect on repelling flies.

The cleaning of the net was easy. The stains came off without using soap and even not much force was applied.

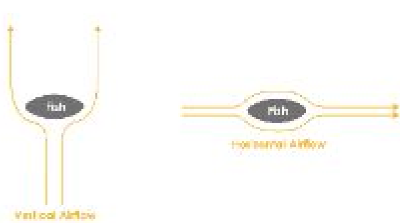
Comparing the horizontal design and the vertical design, some criteria were compared at first.

	The drying rates of different spots on the net	Material needed	Score
Horizontal	**6**	**7** - one chimney & ducting system - two wind-driven fans - short inlet duct - guiding sheet	**13**

Vertical	**9**	**5** - three chimneys & ducting system - three wind-driven fans - long inlet duct	**14**

Then, to validate whether vertical airflow can really dry different layers at a similar rate, a drying test was done.
The test was done on a sunny day for 5 hours. The test setup had three layers with 4 fish on each layer. A constant airflow was supplied from the fan at the bottom (see image below). The weight of each fish was measured every hour.

The test results showed that, even though the bottom layer dried faster than the top layer at the first hour, in the end, three layers reached a certain dryness level at the same hour. Based on this fact, the assumption was validated. However, through observation, the upper side of the fish seemed to be thicker than the bottom side (without turning). The reason might be that the airflow rarely flew to the top surface (see figure below) so that the bottom side dried faster.



Another test should be conducted to validate the assumption. However, the weather in the Netherlands is unpredictable; thus, it has been decided to accept this assumption for now. As the main advantage of vertical airflow seemed less convincing now, the horizontal design was chosen to be the final design for this project.

The other objective of this test is to determine whether the turning operation can be omitted. The original objective of the test was to see whether the fish can be fully dried without turning sides. In this perspective, the test result showed that most likely the fish can be dried without turning. However, when the fish was taken for weight measurement, it was observed that some flesh and skin were stuck on the nets. The sticking situation at the lower layers seemed to be more severe than the higher layers, where the lower layers had faster drying rates at the beginning. According to the test observation, after the first removal at the first hour, the fish no longer had sticking issues. Moreover, Andreas mentioned that flipping the dagaa can prevent it from sticking to the wire mesh. Synthesizing these findings, it was assumed that flipping the fish before a certain dryness level can avoid the sticking situation. In this case, turning is still required, but only once at the beginning. And based on this assumption, in the vertical design, different drying rates of the layers at the beginning may create extra hassles for turning.

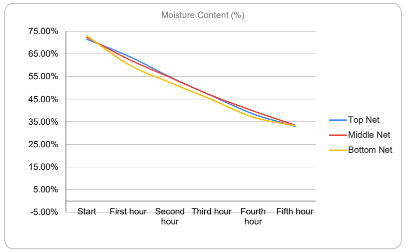
To conclude, it was a dilemma to choose between two designs, as they both have their pros and cons. However, the main feature of vertical airflow is to have equal drying speed on each layer, and now it seems to have some doubt on its performance. Therefore, It was decided to continue with the horizontal design. As for the turning operation, although it cannot be neglected, the fish only have to be flipped once at the early stage to avoid sticking issues.

Appendix R-2 Drying Test Data

Date	21/08/2020	Time	10:05~											
	Initial	10:05	First hour	11:05	Second Hour	12:05	Third Hour	13:05	Fourth hour	14:05	Fifth Hour	15:05	17:00	
Outside Temp	26.5 °C		27.8 °C		32.5 °C		30.2 °C		31.2 °C		30.0 °C			
Inside temp	27.0 °C		33.0 °C		37.0 °C		34.0 °C		36.0 °C		32.0 °C			
Inside Humidity	56%		37%		26%		29%		27%		33%			
	Air Velocity	Temp	Max. air velocity	Temp	Max. air velocity	Temp	Max. air velocity	Temp	Max. air velocity	Temp	Air Velocity	Temp	ax. air velocity (av	Temp (avg.)
Point A	2.38 m/s	27.2 °C	1.59 m/s	32.6 °C	2.67 m/s	32.9 °C	1.77 m/s	34.3 °C		32.5 °C		30.6	2.10 m/s	31.7 °C
Point B	2.93 m/s	27.2 °C	2.42 m/s	32.2 °C	2.34 m/s	32.4 °C	2.92 m/s	33.0 °C		32.2 °C		30.5	2.65 m/s	31.3 °C
Point C	3.58 m/s	27.1 °C	4.32 m/s	31.5 °C	3.36 m/s	32.0 °C	3.84 m/s	32.7 °C		31.8 °C		30.1	3.78 m/s	30.9 °C
Point D	4.32 m/s	27.1 °C	4.40 m/s	31.2 °C	4.32 m/s	32.3 °C	3.99 m/s	32.2 °C		31.4 °C		30	4.26 m/s	30.7 °C

	Weight	Approximate dry matter (70% moisture content)	Actual dry matter	Original moisture content (%)	Target weight (15% moisture content)	Target weight loss(%)	First hour Weight	First hour Moisture content (%)	First hour Weight Loss	Second Hour Weight	Second Hour Moisture content (%)	Second Hour Weight Loss
Fish 1	16.9 g	16.9 g	5.6 g	66.86%	6.4 g	-61.89%	14.0 g	60.00%	-17.16%	11.3 g	50.44%	-33.14%
Fish 2	15.5 g	15.5 g	4.8 g	69.03%	5.5 g	-64.39%	12.7 g	62.20%	-18.06%	10.3 g	53.40%	-33.55%
Fish 3	10.8 g	10.8 g	2.9 g	73.15%	3.3 g	-69.12%	8.5 g	65.88%	-21.30%	6.8 g	57.35%	-37.04%
Fish 4	11.1 g	11.1 g	2.6 g	76.58%	3.0 g	-73.06%	8.1 g	67.90%	-27.03%	6.2 g	58.06%	-44.14%
Avg.	13.6 g	13.6 g	4.0 g	71.41%	4.6 g	-66.33%		64.00%	-20.89%		54.81%	-36.97%
Fish 5	11.6 g	11.6 g	3.4 g	70.69%	3.9 g	-66.29%	8.9 g	61.80%	-23.28%	7.4 g	54.05%	-36.21%
Fish 6	16.2 g	16.2 g	5.5 g	66.05%	6.3 g	-60.96%	12.7 g	56.69%	-21.60%	10.9 g	49.54%	-32.72%
Fish 7	12.7 g	12.7 g	3.2 g	74.80%	3.7 g	-71.02%	9.4 g	65.96%	-25.98%	7.5 g	57.33%	-40.94%
Fish 8	10.2 g	10.2 g	2.3 g	77.45%	2.6 g	-74.07%	6.8 g	66.18%	-33.33%	5.4 g	57.41%	-47.06%
Avg.	12.7 g	12.7 g	3.6 g	72.25%	4.1 g	-67.34%		62.66%	-26.05%		54.58%	-39.23%
Fish 9	14.4 g	14.4 g	4.2 g	70.83%	4.8 g	-66.46%	10.1 g	58.42%	-29.86%	8.5 g	50.59%	-40.97%
Fish 10	11.9 g	11.9 g	3.0 g	74.79%	3.5 g	-71.01%	7.9 g	62.03%	-33.61%	6.5 g	53.85%	-45.38%
Fish 11	15.7 g	15.7 g	4.8 g	69.43%	5.5 g	-64.84%						
Fish 12	14.5 g	14.5 g	3.9 g	73.10%	4.5 g	-69.07%	9.9 g	60.61%	-31.72%	8.2 g	52.44%	-43.45%
Avg.	13.6 g	13.6 g	3.7 g	72.91%	4.3 g	-68.71%		60.35%	-31.73%		52.29%	-43.27%

	Third Hour Weight	Third Hour Moisture content (%)	Third Hour Weight Loss	Fourth hour Weight	Fourth hour Moisture content (%)	Fourth hour Weight Loss	Fifth Hour Weight	Fifth Hour Moisture content (%)	Fifth Hour Weight Loss	17:00	17:00 Moisture content (%)	17:00 Weight Loss	Accomplishment rate (actual weight loss/target weight loss)
Fish 1	9.7 g	42.27%	-42.60%	8.6 g	34.88%	-49.11%	8.0 g	30.00%	-52.66%	7.3	23.29%	-56.80%	85%
Fish 2	8.8 g	45.45%	-43.23%	7.8 g	38.46%	-49.68%	7.0 g	31.43%	-54.84%	6	20.00%	-61.29%	85%
Fish 3	5.6 g	48.21%	-48.15%	4.8 g	39.58%	-55.56%	4.4 g	34.09%	-59.26%	3.8	23.68%	-64.81%	86%
Fish 4	5.2 g	50.00%	-53.15%	4.4 g	40.91%	-60.36%	4.1 g	36.59%	-63.06%	3.6	27.78%	-67.57%	86%
Avg.		46.48%	-46.78%		38.46%	-53.68%	5.9 g	33.03%	-57.46%		23.69%	-62.62%	87%
Fish 5	6.4 g	46.88%	-44.83%	5.7 g	40.35%	-50.86%	5.1 g	33.33%	-56.03%	4.5	24.44%	-61.21%	85%
Fish 6	9.5 g	42.11%	-41.36%	8.6 g	36.05%	-46.91%	7.9 g	30.38%	-51.23%	7.1	22.54%	-56.17%	84%
Fish 7	6.2 g	48.39%	-51.18%	5.5 g	41.82%	-56.69%	5.0 g	36.00%	-60.63%	4.5	28.89%	-64.57%	85%
Fish 8	4.5 g	48.89%	-55.88%	3.9 g	41.03%	-61.76%	3.5 g	34.29%	-65.69%	3.1	25.81%	-69.61%	89%
Avg.		46.56%	-48.31%		39.81%	-54.06%	5.4 g	33.50%	-58.40%		25.42%	-62.89%	87%
Fish 9	7.4 g	43.24%	-48.61%	6.6 g	36.36%	-54.17%	6.1 g	31.15%	-57.64%	5.4	22.22%	-62.50%	87%
Fish 10	5.5 g	45.45%	-53.78%	4.6 g	34.78%	-61.34%	4.4 g	31.82%	-63.03%	3.8	21.05%	-68.07%	89%
Fish 11							7.3 g	34.25%	-53.50%	6.1	21.31%	-61.15%	83%
Fish 12	7.2 g	45.83%	-50.34%	6.5 g	40.00%	-55.17%	6.1 g	36.07%	-57.93%	5.2	25.00%	-64.14%	84%
Avg.		44.84%	-50.91%		37.05%	-56.89%	6.0 g	33.32%	-58.02%		22.40%	-63.96%	84%



Moisture Content (%	Start	First hour	Second hour	Third hour	Fourth hour	Fifth hour
Top Net	71.41%	64.00%	54.81%	46.48%	38.46%	33.03%
Middle Net	72.25%	62.66%	54.58%	46.56%	39.81%	33.50%
Bottom Net	72.91%	60.35%	52.29%	44.84%	37.05%	33.32%

Appendix S Heating and Circulation Iteration 04

Goals

1. Increase the velocity and balance the distribution
2. Rearrange the fans and test the performance
3. Rearrange the chimney and ducting system

Parameters

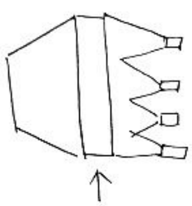
The following table shows the parameters that might affect the heating and circulation performance.

Component	Parameter	Component	Parameter
Heat Pump	Location	Outlet Opening	Location
	Dimension		Dimension
	Specs (power and material)		Specs (form and material of duct)
Greenhouse	Location	Chimney	Location
	Dimension		Dimension
	Specs (material)		Specs (material and amount)
Inlet Fan	Location	Racks	Location
	Dimension		Dimension
	Specs (power, materia,l and amount)		Specs (Rack Layer Height and amount)
Inlet Opening	Location	Heat Exchanger	Location
	Dimension		Dimension
	Specs(form and material of duct)		Specs (number of layers and material)
Outlet Fan	Location		
	Dimension		
	Specs (power and material)		

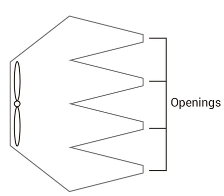
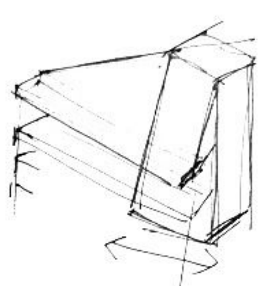
Ideation

The chosen ideas were divided into two groups, concept group, and simulation group. The effects of the simulation group were evaluated by flow simulation.

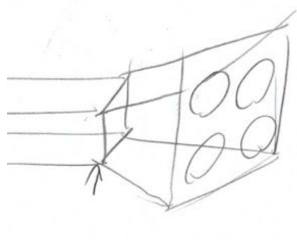
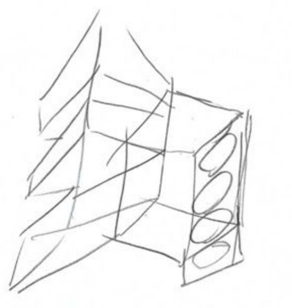
Increase the velocity

Chosen Ideas	Description
Guiding Neck (simulation group) 	The neck aimed to straighten the airflow so that the airflow can go further with higher speed.

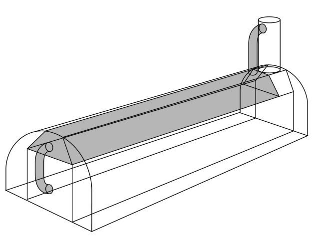
Balance the distribution

Chosen Ideas	Description
Opening Adjusting (simulation group) 	It aimed to balance the distribution by enlarging the openings that received less air.
Wider Bottom (simulation group) 	This idea aimed to increase the airflow at the bottom to even the distribution.

Rearrange the fans and test the performance

Chosen Ideas	Description
2X2 arrangement (simulation group) 	Four fans were arranged in a two-by-two setting.
1x4 arrangement (simulation group) 	Four fans were arranged in a one-by-four setting.

Rearrange the chimney and ducting system

Chosen Ideas	Description	Note
Integrated Chimney (Concept group) 	This idea reduced the needed ducting materials and reduced the blocked sunlight.	Although it may influence the temperature and the airflow, however, considering the time constraint of the project and the accuracy of the simulation, this idea was not simulated.

Prototyping

Simplified 3D models of the simulation group were made in Solidworks for airflow study

Evaluation (Simulation)

At first, the guiding neck was added to the design to test the effect on increasing the velocity (Table 1). Although the velocity was slightly lower, however, the velocity at the top and the bottom seemed to have better performances. Therefore, the guiding neck was kept.

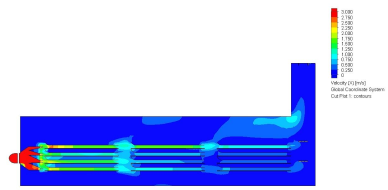
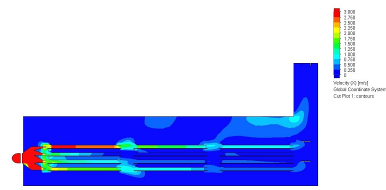
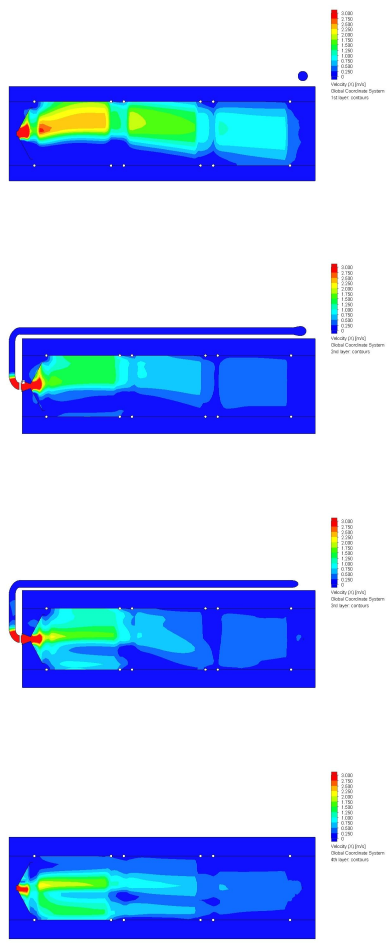
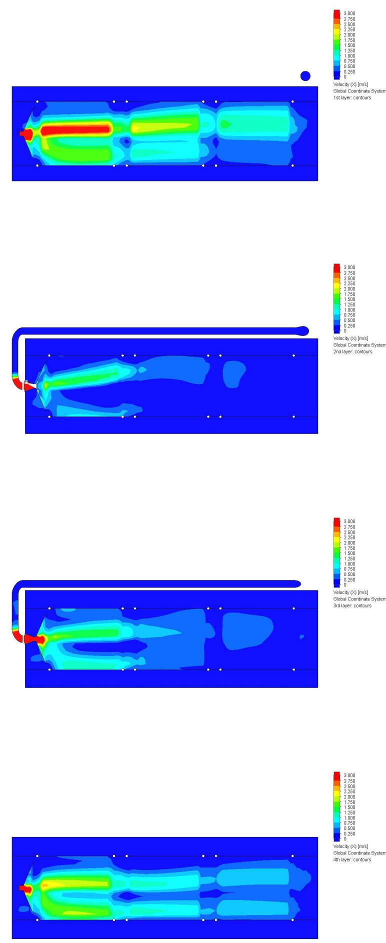
	original	Guiding neck
X-direction Air Velocity (Side View)		
X-direction Air Velocity (All Layers Top View)		
Velocity*	0.660765947351579	0.632000744894223

*Table 1. Velocity Comparison of the design with and without guiding neck (*the values of the velocity do not represent the actual number. It is unitless, and only for comparison)*

Then, to balance the distribution, the openings are adjusted. To check the difference between the design with and without a guiding neck, the same opening adjustments were performed on both models. And the result (Table 2) showed that the guiding neck did help to balance the air distribution (smaller standard deviation means less difference between layers). As a result, both the guiding neck and the opening adjustment were kept.

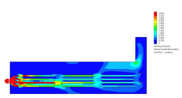
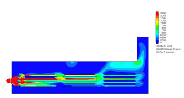
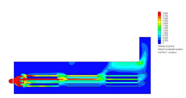
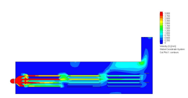
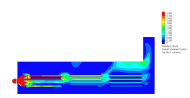
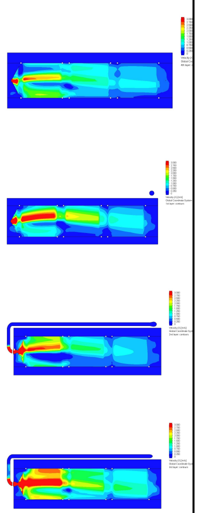
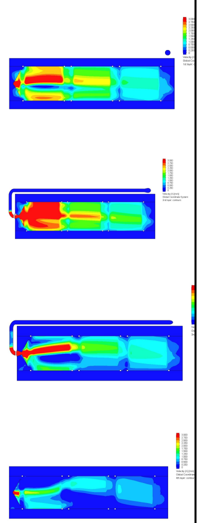
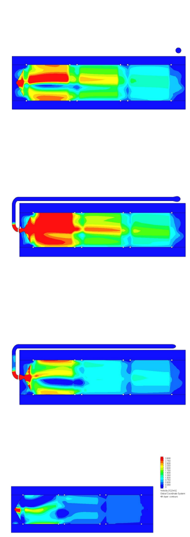
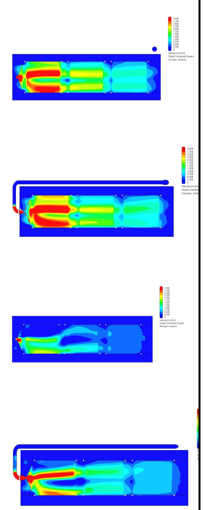
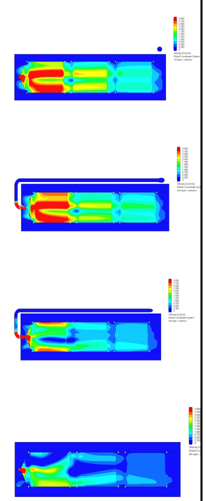
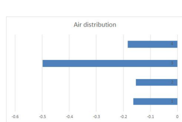
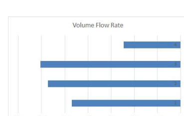
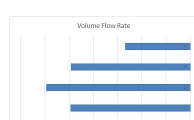
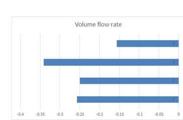
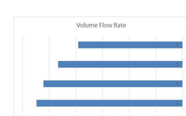
	Original	Opening Adjustment Ver. 1.	Opening Adjustment Ver. 2	Opening Adjustment Ver. 1. (with a Guiding neck)	Opening Adjustment Ver. 2. (with a Guiding neck)
X-direction Air Velocity (Side View)					
X-direction Air Velocity (All Layers Top View)					
Volume flow rate of flour openings					
Standard deviation of four openings	0.166658763	0.081215892	0.068660377	0.075388896	0.034335705

Table 2. Distribution comparison of different inlet duct settings

Next, the shape of the neck was adjusted and simulated (Table 3). The design with a wide-bottom neck had the best result so it was kept.

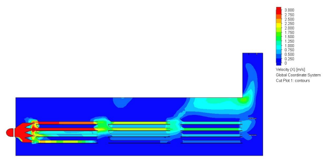
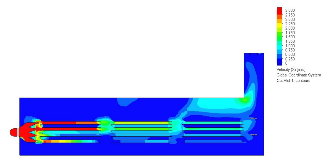
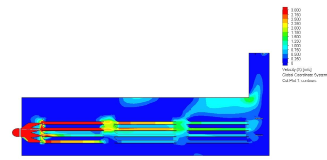
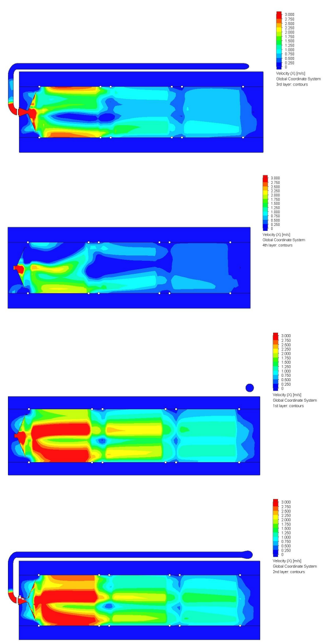
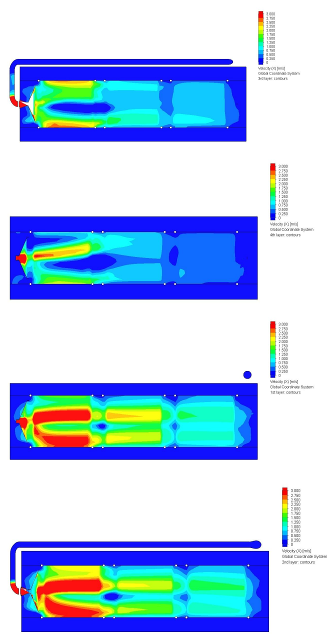
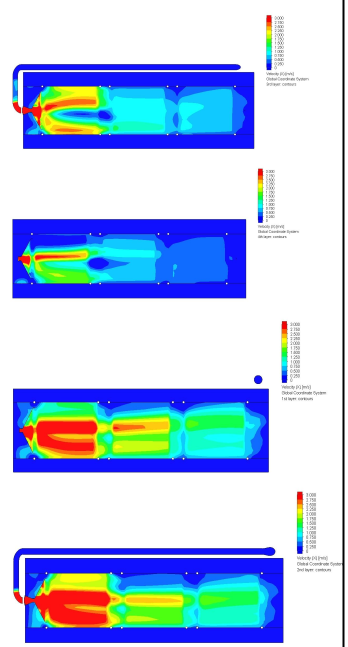
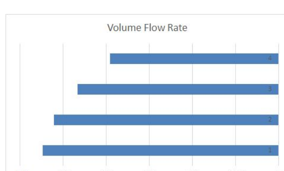
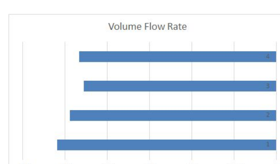
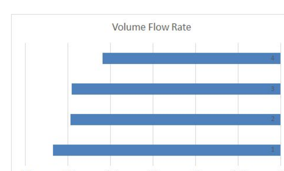
	Opening Adjustment Ver. 2. (with a Guiding neck)	Opening Adjustment Ver. 2. (with wide-bottom guiding neck)	Opening Adjustment Ver. 2. (with wide-bottom guiding neck and extended funnels)
X-direction Air Velocity (Side View)			
X-direction Air Velocity (All Layers Top View)			
Volume flow rate of flour openings			
Standard deviation of four openings	0.034335705	0.014019253	0.024212784

Table 3. Distribution comparison of inlet duct with wide-bottom neck

After the design had been altered, the design was tuned to the actual fan settings. The design marked as “New” in Table 4 is the chosen design from the simulation, i.e., the design of opening adjustment ver. 2. with a wide-bottom guiding neck. Before rearranging the fan, the openings were first adjusted to a result that is closer to the former simulation, i.e., the result in Table 3. While adapting to different fan arrangements, the openings were also adjusted to get better results (Table 5). In the end, the fan arrangement of a 2-by-2 matrix had the best overall performance on distribution and velocity.

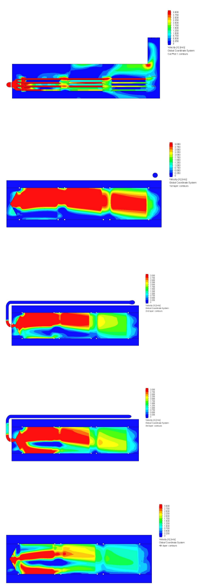
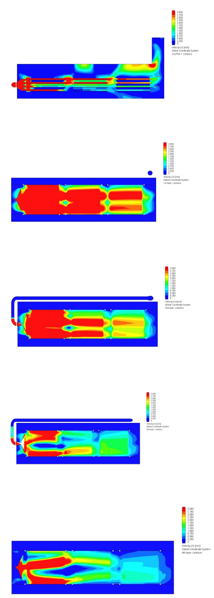
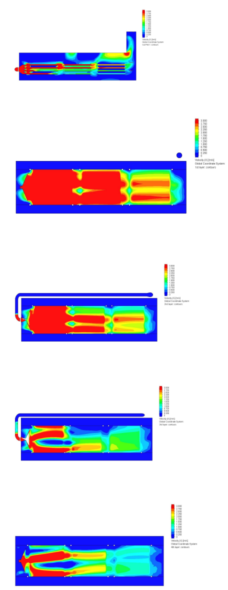
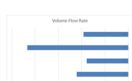
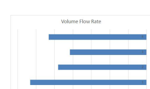
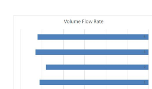
	Original (4 m3/s)	New (4m3/s)	New & opening adjusted (4 m3/s)
X-direction Air Velocity			
Velocity	2.36378705566997	2.502816896	2.49737796065726
Volume flow rate			
SD	0.239080081	0.09137992	0.021181144

Table 4. Comparison between new and original design in actual fan settings

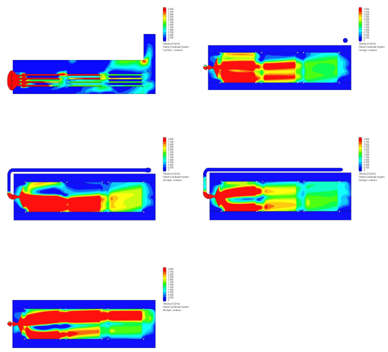
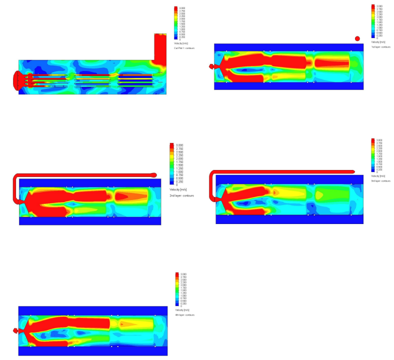
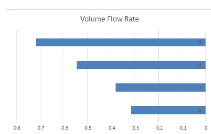
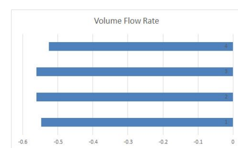
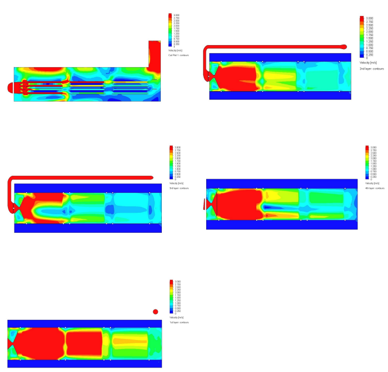
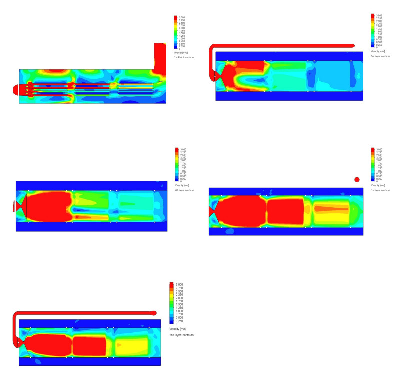
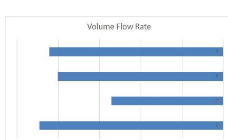
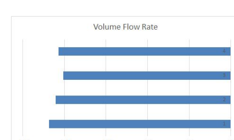
	1*4 arrangement (1 m3/s *4)	1*4 adjusted 4 (1m3/s *4)
X-direction Air Velocity		
Velocity	2.41909245424962	2.13266362467214
Volume flow rate		
SD	0.180184023	0.016895044
	2*2 (1m3/s *4)	2*2 opening adjusted (1m3/s *4)
		
Velocity	2.24638740828709	2.368005324
Volume flow rate		
SD	0.077887312	0.014299966

Table 5. Comparison of different fan arrangements

Conclusion

Final Design

The design consists of a two-meter chimney, a pair of low exhaust fans, a lifted inlet duct with 4 small fans arranged in a 2-by-2 matrix (Fig. 1), insulation layers on the sides, and an integrated ducting system (Fig.2).

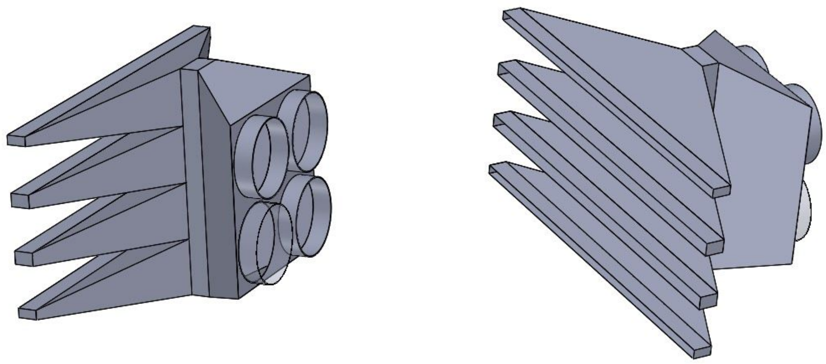


Figure 1. Inlet duct with 4 small fans arranged in a 2-by-2 matrix

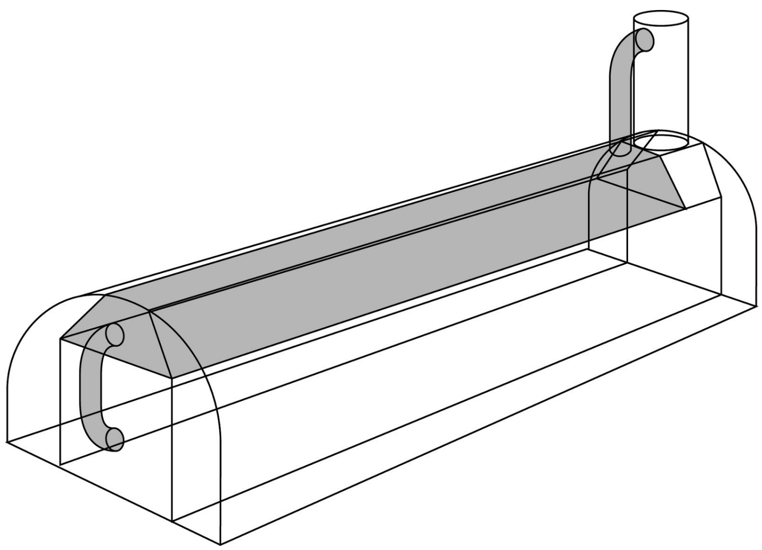


Figure 2. Integrated ducting system

Appendix T-1 Test Plan of Space Saving and Tooling Iteration 01

Objective:

Find out what are the problems (e.g. missing use cues, hard-to-use feature) of the current design to improve the user experience.

Assumptions:

1. Assume the participants of the same height has the same muscle strength and limb lengths as the actual users.
2. Assume the humidity and temperature difference between NL and TZ does not affect the user experience.
3. Assume the weight of the bucket does not affect the user experience

Research questions:

1. How do participants work on the top layer?
2. What is the difference between younger users and older users while performing the tasks?
3. What are the obstacles during the spreading and collecting phase?

Method:

Participants:

4 participants, 1.6-1.7m tall female, age 20~29

Stimulus:

1:1 prototype

Paper fish(rolled into chunks)

Apparatus:

Filming the movement. Digital survey. Audio recorded interview.

Procedure:

Research location: TU Delft IDE Faculty

Research (Stimulus) setup:

The structure of the rack stands in the middle of the aisle with all nets hanging on one pole. Paper fish are collected in two buckets right next to one of the poles.

Instruction:

1. This is a project about sardine drying. Imagine you're a worker in the fish industry in a developing country. You used to deal with a huge amount of sardine every day. The process is to spread the fish under the sun, check the dryness of the fish, and then harvest the dried fish. The whole process

would normally take 6 hours long. Now there's a new product for you to try out.
2. This test consists of two parts: operation and interview. it will last about 10-15 mins.
3. The operation is to spread the paper fish evenly on each layer, check the dryness of each layer, and harvest the dried fish.
4. I will (The observer) perform the operation to you first. Please take it as a reference, try to follow it, but you're allowed to adjust to a way you think is better.
5. The operation is a two-worker task, so I'll be working with you. While setting up the net. And harvesting. (after two layers, change the side)
6. The process will be video recorded just for observation.
7. Please note that there's no right or wrong. If you feel that you're doing something wrong, that would be the problem of the product, not yours, so don't worry.
8. The spreading operation will only be performed on one side.
9. I'll remind you to "load the fish", "spread the fish", "check the dryness" and "collect the fish"
10. After the operation, I'll ask you to fill out a survey of only 10 questions.
11. Afterward, I'll discuss a little bit about your opinion of the product.
12. Any answer would be appreciated. Just be direct, talk about what you feel. It won't hurt my feelings.

Storyboard:

1. Place the first net in place.
2. Take one bucket.
3. Spread the fish with hands onto the first layer (half bucket)
4. hang the next layer.
5. Spread the fish
6. Repeat 4-5 until 4 layers are done
7. Check the dryness of each layer
8. Remove the net from the poles
9. Wrap the fish with the net
10. Pour the fish into the buckets
11. Repeat 8-10 until 4 layers are done

Survey:

https://forms.gle/8usHz7FRB5AzpQL46

Interview:

Ask why if strongly agree was selected for even-numbered questions or strongly disagree was selected for odd-numbered questions. e.g.ask why when the participant chose they strongly disagree on question 1. (note: make a note when they're answering the above questions, and ask questions in the end)

End of the research:

When the desired amount of participants is reached.

Limitation:

1. Experience of the Participants (No comparison)
2. The educational level of the participants
3. Texture & Weight & amount of the fish

Results:

See Appendix T-2 for survey data.

Appendix T-2 Responses of Space Saving and Tooling Iteration 01

Timestamp	Height	Age	Other conditions	01. I think that I would like to use this system frequently.	02. I found the system unnecessarily complex.	03. I thought the system was easy to use.	04. I think that I would need the support of a technical person to be able to use this system.	05. I found the various functions in this system were well integrated.	06. I thought there was too much inconsistency in this system.	07. I would imagine that most people would learn to use this system very quickly.	08. I found the system very cumbersome to use.	09. I felt very confident using the system.	10. I needed to learn a lot of things before I could get going with this system.	Follow up discussion
7/7/2020 12:21:03	165-170	20-29		4	1	3	1	5	2	5	3	5	1	1. confusion of long and short side (color coding 2. collection work can be simplified (e.g. relocate the bucket, work on only one pole) 3. it's easier to move the fish to one side instead of the middle for collection. 3. hard to check the middle of the highest layer (but by checking the second layer we can already know if the first layer is dried) 4. Fish can get stuck in the net 5. The net is easy to slip off the hook (because of the hook angle)
7/7/2020 15:06:05	165	20-29		5	2	5	1	4	1	5	2	4	1	1. While checking the dryness, the participant's hair is touching the upper layer. She assumed that the workers will not minc the smelling, but she also didn't want to flip and ruin the upper later 2. It's hard to reach the middle of the highest net (maybe need a stick or something). 3. It'd be good if the height can be adjusted. 4. The net could have a (number) coding/guide for the designate hook. 5. It feels steady and strong enough to hold her back while checking the fish 6. It feels bright and open than the original design. (claustrophobia) 7. The participant tried two ways of collecting (i. folding as instruction, ii. gather the fish to the middle and collect it but this way spilled more out) 8. The participant tried to shake the net to spread the fish evenly (it doesn't work as expected).
7/9/2020 11:00:12	160-164	20-29		4	2	3	3	4	2	5	3	4	2	1. Layer height difference is a problem. if the layer can be switch easier for spreading that'll be better 2. Square net will solve the problem of different length 3. it'll be easier to spread the fish with a tool (on the higher layer) 4. The participant got tired from the third layer 5. The net is too flexible. Sometimes it's hard to control. (foldable rigid net would be better) 6. She would like to set the net first then spread the fish later. 7. The participant tried to shake the net to spread the fish
7/9/2020 11:10:16	160-164	20-29		4	2	3	3	4	2	5	3	4	2	1. Layer height difference is a problem. if the layer can be switch easier for spreading that'll be better 2. Square net will solve the problem of different length 3. it'll be easier to spread the fish with a tool (on the higher layer) 4. The participant got tired from the third layer 5. The net is too flexible. Sometimes it's hard to control. (foldable rigid net would be better) 6. She would like to set the net first then spread the fish later. 7. The participant tried to shake the net to spread the fish 8. It feels like it's not a difficult task, everyone can do. even without skills

Appendix U-1 Test Plan of Structure & Isolation Iteration 01

Objective:
Find out whether the space between the wall and the racks is enough for working.
Find out whether the insulation layer hinders user activity.

Assumptions:
1. Assume the participants of the same height has the same muscle strength and limb lengths as the actual users.
2. Assume the humidity and temperature difference between NL and TZ does not affect the user experience.
3. Assume the weight of the bucket does not affect the user experience

Research questions:
1. Do the greenhouse walls hinder the movement when performing the tasks?
2. What are the obstacles when rolling the door/insulation layer?

Method:

Participants:

5 participants, 150 - 193 cm tall female, age 20~39

Stimulus:

1. 1:1 prototype of the rack
2. Paper fish(rolled into chunks)
3. 1 section (3-meter-long) of the greenhouse + insulation layer + door

Apparatus:

Filming the movement. Digital survey. Audio recorded interview.

Procedure:

Research location: TU Delft/IDE/PMB lab

Research (Stimulus) setup:

A 4 x 3 x 2.5 m (WxLxH) greenhouse setup standing in the middle of the courtyard. To save some time, the tubes are not bent. In order to mimic the dome, hemp ropes are used to support the PE film (both the greenhouse cover and the insulation layer), but only on one side of the installation. The rack is placed in the middle of the greenhouse with all nets hanging on one side of the rack (the short side of the net is connected to two poles at the front). Paper fish are collected in a bucket right next to one of the poles.

Instruction:

1. This is a project for sardine drying. Imagine you're a worker in the fish industry in a developing country. You used to deal with a huge amount of sardine every day(show pic). The process is to spread the fish under the sun, check the dryness of the fish, and then harvest the dried fish. The whole process would normally take 6 hours long. Now there's a new product for you to try out.
2. This test consists of two parts: operation and interview. it will last about 10-15 mins.
3. The operation is to enter the greenhouse and roll up the cover layer. Then, spread the paper fish evenly on each layer, check the dryness of each layer, and harvest the dried fish.
4. I (The observer) will perform the operation to you first. Please take it as a reference, try to follow it, but you're allowed to adjust to a way you think is better.
5. The operation is a two-worker task, so I'll be working with you. While setting up the net. And harvesting. (after two layers, change the side)
6. The process will be video recorded just for observation.
7. Please note that there's no right or wrong. If you feel that you're doing something wrong, that would be the problem of the product, not yours, so don't worry.
8. The spreading operation will only be performed on one side.
9. After the operation, I'll ask you to fill out a survey of only 10 questions.
10. Afterward, I'll discuss a little bit about your opinion of the product.
11. Any answer would be appreciated. Just be direct, talk about what you feel. It won't hurt my feelings.

Storyboard:

Spreading

1. Walk into the installation
2. Roll up the insulation layer
3. Place the first net in place.
4. Take one bucket.
5. Spread the fish with hands onto the first layer (half bucket)
6. hang the next layer.
7. Spread the fish
8. Repeat 4-5 until 4 layers are done
9. Put down the insulation layer
10. Walk out the installation
11. Put down the door

Checking

12. Walk into the installation

13. Roll up the insulation layer
14. Check the dryness of each layer
15. Put down the insulation layer
16. Walk out the installation

Harvesting

17. Walk into the installation
18. Roll up the insulation layer
19. Remove the net from the poles
20. Wrap the fish with the net
21. Pour the fish into the buckets
22. Repeat 8-10 until 4 layers are done
23. Put down the insulation layer
24. Bring the buckets out (depends on the process. Ask SES how would the processors do? One by one or all in once)

Survey:
https://forms.gle/Vw3W8ZCobbNp63wp9

Interview:

Ask why if strongly agree was selected for even-numbered questions or strongly disagree was selected for odd-numbered questions. e.g.ask why when the participant chose they strongly disagree on question 1. (note: make a note when they're answering the above questions, and ask questions in the end)

End of the research:

When the desired amount of participants is reached.

Limitation:

1. Length difference (not full-size) may affect the experience
2. None-close space may affect the experience
3. The perception of the curved-tube-formed and hemp-rope-formed dome may differ.
4. Experience of the Participants (No comparison)
5. The educational level of the participants
6. The size and weight of the bucket may affect.
7. The humidity and temperature are different from the actual situation the perception might be affected.

Result:

See Appendix U-2 for survey data.

Appendix U-2 Responses of Structure and Isolation Iteration 01

Timestamp	Height	Age	Other conditions	01. I think that I would like to use this system frequently.	02. I found the system unnecessarily complex.	03. I thought the system was easy to use.	04. I think that I would need the support of a technical person to be able to use this system.	05. I found the various functions in this system were well integrated.	06. I thought there was too much inconsistency in this system.	07. I would imagine that most people would learn to use this system very quickly.	08. I found the system very cumbersome to use.	09. I felt very confident using the system.	10. I needed to learn a lot of things before I could get going with this system.	Follow up discussion
7/23/2020 12:05:42	150-154	20-29		3	4	4	1	4	2	5	1	5	1	1. Doesn't feel oppression from the wall while performing the tasks. especially the space is bright. 2. The cover is too high to reach and takes too much time to roll 3. It would be nice if the bottom-top rolling can be replaced by curtain mechanism which makes it easier to use (can be horizontal rolling) 4. The participant tried several different ways to collect the fish. She tried to move the bucket around, and raise it up and down. in the end she placed it on the lower layer, as it prevents fish from spilling.
7/23/2020 13:54:35	160-164	30-39	back pain	4	2	3	1	4	2	5	3	4	1	1. The participant has back pain but she didn't feel the pain during the operation 2. The top layer is a bit too high to reach 3. The rolling movement is easy at the bottom, but cumbersome when the rolling movement is above shoulder. 4. The participant didn't want to roll the cover up to check the dryness, 'cause it's too much work. 5. If the work would be done in a short period, the rolling task of the insulation layer won't bother. but if she has to do it for the whole day and for many times a day, that'll be a problem. 6. The participant didn't feel oppression, but she said that she might feel differently if it's on the beach with all that heat. 7. The work can be symmetric, so one person doesn't have to wait for the other while harvesting. 8. The net is touching the ground, which is not hygienic.
7/23/2020 16:32:05	155-159	20-29	hair bun	4	3	4	2	5	2	5	1	5	1	1. Rolling is not so difficult. but the stick can be thicker for better grip. maybe a rounded shape would be even better 2. She's afraid of spikes on the wood stick 3. She slid herself in between the insulation layer and the rack to check the dryness. 4. She felt some oppression but just a little bit. But she thought that the light color makes it bright so she didn't feel so much of the oppression. 5. The drying net is touching the ground which is not hygienic. 6. The participant found a new way of collecting fish: pour the fish to the lower layer and collect it all in once from the bottom layer. 7. The participant is expecting some fun things to play with (like surprises printed on the nets/poles or something like that) to ease the boring life.
7/24/2020 15:38:22	165-170	20-29		3	1	3	1	4	1	5	4	5	1	1. rolling down is not cumbersome, but rolling up is bothering. 2. She gave some advice one how to roll the sheet. (triangular fold, rolling blind, angled rail, hooks on the poles) 3. The space is quite enough. didn't feel any oppression. 4. the participant drop the nets on the ground without thinking on the hygienic issue.
7/24/2020 15:45:45	193	20-29	lower back issues	2	1	5	1	5	1	5	1	5	1	1. Lower back issue is affecting only when rolling the layer. collecting fish is not a issue as the participant can squat. 2. The participant gave some ideas for dryness checking (e.g. openings on each layer) 3. The participant didn't feel oppression in the aisle 4. the participant was bothered by the beams on the racks, but as it is a two-worker task and the beams were in the shape of a cross so it didn't bother too much.

Appendix V-1 Test Plan of Structure and Isolation Iteration 01

Objective:

Improve the user experience of the insulation layer.

Assumptions:

1. Assume the participants of the same height has the same muscle strength and limb lengths as the actual users.
2. Assume the humidity and temperature difference between NL and TZ does not affect the user experience.
3. Assume the weight of the bucket does not affect the user experience

Research questions:

1. What are the obstacles when rolling the insulation layer?
2. How much faster is the current design compared to the previous design?

Method:

Participants:

5 participants, 150 - 193 cm tall female, age 20~39

Stimulus:

1. 1:1 prototype of the rack
2. Paper fish(rolled into chunks)
3. 1 section (3-meter-long) of the greenhouse + insulation layer

Apparatus:

Filming the movement. Digital survey. Audio recorded interview.

Procedure:

Research location: TU Delft/IDE/PMB lab

Research (Stimulus) setup:

A 4 x 3 x 2.5 m (WxLxH) greenhouse setup standing in the middle of the courtyard. To save some time, the tubes are not bent. In order to mimic the dome, hemp ropes are used to support the PE film (both the greenhouse cover and the insulation layer), but only on one side of the installation. The rack is placed in the middle of the greenhouse with the first three layers set and the top layer hanging on one side of the rack (the short side of the net is connected to two poles at the front) (pic). Paper fish are collected in a bucket right next to one of the poles.

Introduction:

Instruction:

1. This is a project for sardine drying. Imagine you're a worker in the fish industry in a developing country. You used to deal with a huge amount of sardine every day(show pic). The process is to spread the fish under the sun, check the dryness of the fish, and then harvest the dried fish. The whole process would normally take 6 hours long. Now there's a new product for you to try out.
2. This test consists of two parts: operation and interview. it will last about 5-10 mins.
3. The operation is to enter the greenhouse and roll the cover layer up and down.
4. The process will be video recorded just for observation.
5. Please note that there's no right or wrong. If you feel that you're doing something wrong, that would be the problem of the product, not yours, so don't worry.
6. The spreading operation will only be performed on one side.
7. After the operation, I'll ask you to fill out a survey of only 10 questions.
8. Afterward, I'll discuss a little bit about your opinion of the product.
9. Any answer would be appreciated. Just be direct, talk about what you feel. It won't hurt my feelings.

Procedure:

Spreading

1. Walk in the installation
2. Pull up the insulation layer
3. Set the top layer of the drying rack.
4. Put down the insulation layer
5. Walk out the installation

Checking

6. Walk into the installation
7. Pull up the insulation layer
8. Check the dryness of each layer
9. Put down the insulation layer
10. Walk out the installation

Harvesting

11. Walk into the installation
12. Pull up the insulation layer

Survey:

https://forms.gle/mPvJAiFhgnjW67kC9

Timing:

The act of pulling up and putting down the insulation layer will be performed 3 times and video recorded. The average time will be compared to the time used in the previous test.

Interview:

Ask why if strongly agree was selected for even-numbered questions or strongly disagree was selected for odd-numbered questions. e.g.ask why when the participant chose they strongly disagree on question 1. (note: make a note when they're answering the above questions, and ask questions in the end)

End of the research:

When the desired amount of participants is reached.

Limitation:

1. Length difference (not full-size) may affect the experience
2. None-close space may affect the experience
3. The perception of the curved-tube-formed and hemp-rope-formed dome may differ.
4. Experience of the Participants (No comparison)
5. The educational level of the participants
6. The size and weight of the bucket may affect.
7. The humidity and temperature are different from the actual situation the perception might be affected.

Note:

1. To not bias the participant, i.e. to prevent the participants from speeding up, they're not told that the operation is timed.
2. Between pulling up and down, the participants are given some tasks to do to reduce the condition difference between two tests (which may affect the result)

Result:

See Appendix V-2 for survey data and the time records.

Appendix V-2 Responses of Structure and Isolation Iteration 02

Timestamp	Height	Age	Other conditions	01. I think that I would like to use this system frequently.	02. I found the system unnecessarily complex.	03. I thought the system was easy to use.	04. I think that I would need the support of a technical person to be able to use this system.	05. I found the various functions in this system were well integrated.	06. I thought there was too much inconsistency in this system.	07. I would imagine that most people would learn to use this system very quickly.	08. I found the system very cumbersome to use.	09. I felt very confident using the system.	10. I needed to learn a lot of things before I could get going with this system.	Follow up discussion
7/28/2020 12:56:47	165-170	20-29		5	1	5	1	4	2	5	2	4	1	1. it is a lot easier than rolling up 2. The flap didn't hinder that much, but if it does, she wouldn't mind to roll the flap up again. 3. hesitated when the cover didn't move upwards 4. it could be smoother
7/28/2020 12:59:25	193	20-29	lower back issue	5	3	4	1	5	1	5	1	5	1	1. The bar on top blocked the participant's vision 2. There's some hesitation while rolling up, but the participant shakes the cover to speed it up. 3. it is better than manual roll-up design. 4. The participant rolled a little bit before pulling because the participant's afraid of breaking it.
7/28/2020 14:15:22	160-164	30-39		5	2	5	1	4	1	5	1	5	1	1. the hanging flap is not bothering too much 2. The smoothness should be improved 3. Still would like to slip through the gap then lift up the curtain. But if no squat is needed. 4. would need a step for working on the top layer.
7/28/2020 15:22:23	150-154	20-29		5	3	4	1	5	1	5	1	5	1	1. The flap hanging there is somehow bothering because it is not above the head. 2. The mechanism is cool 3. Rolling up is still a bit troublesome, but much better than before. 4. It looks a little bit hard to reach the top.
7/28/2020 16:45:28	150-154	20-29		5	1	4	1	4	1	5	1	5	1	1. Need to stand on her toes to hang the bar 2. The delay of the rolling is creating hesitation 3. if the task can be done without squatting or bending would be nice 4. can't help imagine workers with babies

Rolling Time Record

Participant	Previous design						New design					
	roll up			roll down			roll up			roll down		
	1st	2nd	Avg.	1st	2nd	Avg.	1st	2nd	Avg.	1st	2nd	Avg.
A	36.00 Seconds		36.00 Seconds	8.00 Seconds		8.00 Seconds	20.00 Seconds		20.00 Seconds	10.20 Seconds		10.20 Seconds
B	29.01 Seconds		29.01 Seconds	7.80 Seconds		7.80 Seconds	9.50 Seconds		9.50 Seconds	14.00 Seconds		14.00 Seconds
C	37.60 Seconds		37.60 Seconds	9.40 Seconds		9.40 Seconds	12.10 Seconds	13.40 Seconds	12.75 Seconds	12.60 Seconds	9.40 Seconds	11.00 Seconds
D	42.90 Seconds		42.90 Seconds	11.70 Seconds		11.70 Seconds						
E	49.20 Seconds	41.00 Seconds	45.10 Seconds	10.20 Seconds	8.70 Seconds	9.45 Seconds	12.20 Seconds	10.20 Seconds	11.20 Seconds	11.70 Seconds	7.00 Seconds	9.35 Seconds
F							8.50 Seconds	8.50 Seconds	8.50 Seconds	14.90 Seconds	9.80 Seconds	12.35 Seconds
G	17.20 Seconds		17.20 Seconds	18.20 Seconds		18.20 Seconds						
		Avg.	34.64 Seconds		Avg.	10.76 Seconds		Avg.	12.39 Seconds		Avg.	11.38 Seconds

Appendix W Bill of Materials and Cost-Profit Analysis

Subsystem	Part no.	Name	Description	Material	Life Time (year)	Quantity	Cost per pice (€)	TOTAL COST (€)
Structure & Insulation & Restriction	1	Greenhouse Frame - main body (D 48,42- L 6683.185)	Frame of the main body	Galvanized Steel Tube	20	5	26.73	133.7
	2	Greenhouse Frame - Purlin (D 48,42- L 12000	top support of the greenhouuse	Galvanized Steel Tube	20	2	48.00	96.0
	3	Greenhouse Frame - Chimney (1mx1mx2m - 5cm thickness)	Chimney	Pine wood plank	5	1	4.16	4.2
	4	Greenhouse Frame Support (60x60x2.5)	Joint for the frame and the base	Galvanized Steel Tube	20	10	3.20	32.0
	5	Greenhouse Base [200x32]	A base to support the frame	Pine wood plank	3	1	33.28	33.3
	6	Greenhouse Covering Material (100 sq. m 155μm)	To cover the frame and create an indoor space	HDPE	3	1	72.00	72.0
	7	Wiggle wires & rails	To fixate the covering material on the frame	Steel & Aluminium	4	44 m	0.42	18.5
	8	Weights	To seal the gaps between the body and the ground.	Anything available		32 m	0.00	0.0
	9	Greenhouse door	To allow people to get in	Metal Zippers	2	8 m	1.00	8.0
	10	Insulation Curtains (3m x 3m)	To divide the greenhouse into three chambers	HDPE	5	6	6.48	38.9
	11	Infiltration-preventing layer (90 cm x 3 m x 4pcs/140cm x 3m x 4pcs)	To prevent infultration between curtains	HDPE	5	4	4.97	19.9
	12	Insulation Curtains End Weights (D 20, L 3000mm)	Attached to the end of the curtain for user interation and sand sealing	Round wood stick	15	6	0.90	5.4
	13	Pulley Weights (D30, L3000mm)	For the opening mechanism of the curtains	Round wood stick	15	6	1.56	9.4
	14	Weights	To seal the gaps between the infiltration preventing layers and the ground.	Anything available		9 m	0.00	0.0
	15	Insulation Pulley (Fixed bar) (D28, L3000mm)	The fixed part of the pulley system	Round wood stick	20	6	1.56	9.4
	16	Ducting system (D40cm)	For air recirculation	Galvanized Steel	10	4 m	25.00	100.0
	17	Chimney Joint (450mm x 450 mm + D40 100mm cylinder)	To connect chimney and the duct	0.75mm Steel	10	4	5.00	20.0
	18	Air Distributor support , Insulation support , duct joint support (20cm x 3.2cm)	To fixate the air distributor	Pine wood plank	10	1	10.40	10.4
	19	Screws	Connceting the wood planks	Steel	15	1	30.00	30.0
	20	Bolt and nuts (M10x60mm, M10x100mm,	To connect frames and top support. To connect base and frame support.	Steel				
	21	Long bolts	To connect the fixed bar of the pully system and the frame	Steel				
	22	Tape/double sided tapes	To joint two PE sheets and to connect the sheet to the planks					
Space Saving & Tooling	23	Retired fishing net (Mesh size 8mm)	For holding the fish	Nylon	1	4	4.00	16.0
	24	Elastic bands (3cm x 310m)	Drying net	Polyester	1	4	2.50	10.0
	25	Hanging Poles (6.8x6.8x180cm)	To hold the nets	Pine wood square sticks	5	12	1.87	22.5
	26	Screw Hooks	To hang the nets	Galvanized Steel	3	48	1.00	48.0
	27	Top supports (5x5x390cm+2.5x2.5x300cm)	To stablize the poles & to rest the insulation curtains	Pine wood beam	3	6	4.58	27.5
	28	Base plates (2.5mm, 50 x 50cm)	To fixate the poles	steel plates	5	12	10.00	120.0
	29	L-shaped Brackets (30x20x3mm, Length 40mm)	To fixate the poles	Steel	5	48	0.11	5.5
	30	Guiding sheet	To guide the airflow	HDPE	3	1	21.60	21.6
	31	Screws						0.0
								0.0
Heating & Circulation	32	Plate heat exchanger (50x50mm, thickness 0.5 mm, gap size 10mm)	To reuse the heat from the recirculated air	Wind-driven Fans - Bearings	5	1	180.00	180.0
	33	Heat exchanger supports (10x10xx500mm)	To separate each layer	Pine wood	5	180	0.56	101.4
	34	Heat Pump 9.5 kW/19A/25L per hour dehumidification rate/R134A(4KG)/165*105.6*128cm	To generate heat and dehumidify during rainy days	not specified	15	1	1000.00	1000.0
	35	Ourter casing	A case to stop heat exchanger, desiccant layer/heat pump. And allows fresh air to enter when needed.	1.5 mm Stainless Steel	15	10.41 m2	25.00	260.3
	36	Ourter casing - rubber strips	To increase the water resistance	Rubber	2	1	5.00	5.0
	37	Desiccant	To dehumidify in Sunny days	Silica Gel	3	100	1.25	125.0
	38	Dessicant holder (50x50cm, mesh sixe 1.5mm)	To hold the desiccant	Cotton mesh	2	100	1.20	120.0
	39	Dehumidification layer frame (1cm x 2 cm x 50 cm)	To hold the mesh	Wood+ screw	3	200	0.70	139.6
	40	Hygrometer	To determine whether to open the valve	not specified	10	2	2.00	4.0
	41	Wind-driven Fans	To help chimney effect	Galvanized Steel	3	1	60.00	60.0
	42	Wind-driven Supports (beams and base)	To support the fan	Galvanized Steel		1		
	43	Wind-driven Fans - Bearings (I.D. 40mm O.D. 90mm W23mm	To allow the fan to spin	Stainless steel		2		
	44	Wind-driven Fans - Wind turbine Blades	To capture wind from all direations	Stainless steel		1		
	45	Wind-driven Fans - blades	To create airflow	Alumiium		2		
	46	Air distributor	To distribute the air into 4 laminar airflows	Galvanized Steel 0.75mm	5	9.25 m2	15.00	138.8
	47	Fans - 300W - D40, 3600m3/h	For Air distributor	not specified	5	4	24.80	99.2
	48	PV panel - 400w	To supply energy to fans and the heat pump	not specified	15	40	200.00	8000.0
	49	Electricity storage -150V - 100Ah	To store electricity for the heat pump and fans	not specified	10	2		0.0
	50	Heat Storage	To store heat when heat pump is absent	Any disposed water bottle		400L	0.00	0.0
								0.0
Miscellaneous	51	Manufacturing/assmebleing labors	To manufacture UpWind (including bending, metal cutting, etc.) & to assemble		20	1	1500	1500.0
Tot.	-	-	-	-	-	-	**Total amount**	**12645.1**
							Total amount (shared components deducted)	5985.1

Appendix Y Assembly Steps of UpWind

Greenhouse Base

1. Flatten the sand of the location to install UpWind. Press the sand to make it flat and steady.
2. Assemble the wooden base and place it on the ground to form a rectangular.

Greenhouse Frame

3. Dig holes to insert the ground tubes into the sand at the designated location.
4. Connect the ground tubes to the greenhouse base.
5. Insert the feet of the hoops into the ground tubes
6. Connect the purlins to the top of the hoops with bolts and nuts.
7. Screw the curved wiggle wire rails to the hoops.

Greenhouse Facades

8. Connect the wooden vertical supports to the hoops and the base with bolts and nuts.
9. Bolt the other planks to the designated location (see technical drawings).
10. Screw the straight wiggle wire rails to the designated location of the front wooden support.

Chimney

11. Connect the wooden sticks together through brackets and screws.
12. Bolt the chimney to the purlins.

Greenhouse Cover

13. Cover the main body and the facade with the film, separately.
14. Lock the film with wiggle wires
15. Seal the sides into the sand with weights.
16. Cover the chimney with films after the wind-driven fans are installed.
17. Connect the film of the chimney to the main body with tapes.

Wind-driven Fans

18. Screw the mounting plates to the chimney.
19. Place the base on the ground.
20. Insert the tube through the top and the bottom bearings
21. Screw the bearings tight to the pole.
22. Bolt the fan blades and wind turbine blades to the pole (cover the PE film for the chimney before this step)

Air Distributor

23. Bolt air distributor to the support poles.
24. Screw the air distributor to the facade planks.

Drying Nets

25. Screw the stainless steel hooks on the wooden poles at designate height.
26. Screw the poles to the bases.
27. Insert the top supports into the poles.
28. Reinforce the connection between top support and the poles with brackets.
29. Screw the horizontal bars to the poles on the longer edge of the drying net setup.
30. Hook the hanging loops of the fishing nets to the poles.

Internal partitions (Insulation Curtains)

31. Bolt the wooden stick to the purlin.
32. Fix one end of the curtain to the purlin.
33. Place a wooden stick on the curtain, between the purlin and the bolted wooden, to form a pulley system (see technical drawings).
34. Fix a wooden stick to the other end of the curtain.
35. Repeat 6 times

Internal partitions (Insulation walls)

36. Tape the flaps onto the precut PE film.
37. Fix the top of the wall to the purlin.
38. Tape the side of the walls to the poles of the drying nets.
39. Tape the side of the end walls to the facade wood planks.
40. Fix the other end of the wall to any available objects and bury it in the sand.
41. Repeat untill four mid walls and two end walls are done

Internal partitions (Top guiding sheet)

42. Tape the sides of the sheet to the horizontal top support of the drying nets and the insulation walls.
43. Tape one end of the sheet to the facade wood plank and the other end to the second hoop.

Heating and Dehumidification System

44. Place the casing onto the pallets.
45. Install the hygrometer in place.
46. Install the heat exchanger into the casing and then bolt the lid on.
47. Install the heat pump and bolt it tight on the sides.
48. Place the desiccant layers on the brackets.

Heat Storage

49. Spread the bottles inside the drying chamber evenly.

Power supply

50. Install the PV panels.
51. Connect the panels to the heat pump and the fans.