



# Energieffektivisering ved tunnelindfrysning

ELFORSK projekt no. 348-036  
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# Dagsorden

- Introduktion
- Resultater
- Ny karton tunnelindfryser
- Konklusions

A photograph of a complex industrial ceiling or ductwork system. It features a network of large, metallic pipes, some with insulation, and several rectangular metal ducts. A prominent blue cylindrical component, possibly a filter or pump, is mounted on one of the pipes. The ceiling is supported by a grid of steel beams and has a light-colored, textured surface.

# 1

# Introduktion



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# Projektdeltagere



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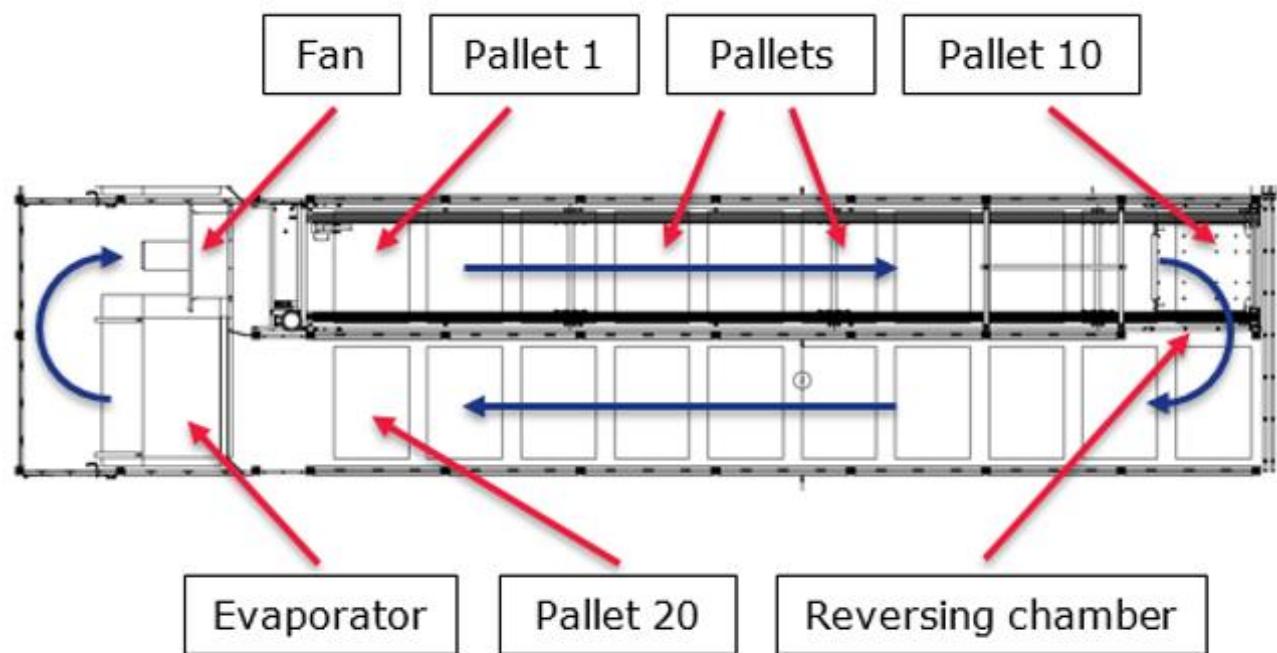
CLAUS SØRENSEN A/S



ELFORSK



# Hvad er en karton tunnelindfryser?



# Hvad var målene med projektet?

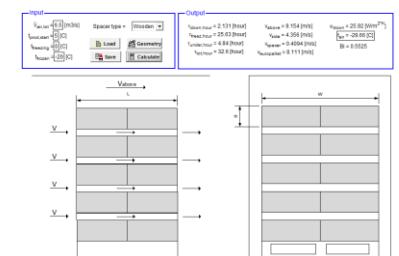
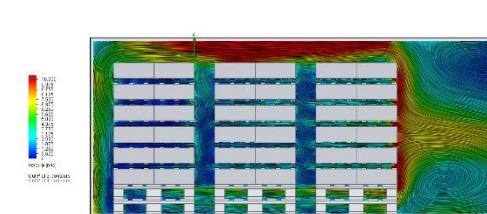
- Energibesparelser
  - 30% besparelse i energi
  - Udvikle ny type af karton tunnelindfryser
- Hvordan?
  - 1 – Luftflow i tunnellen
  - 2 – Luftfordeling i tunnellen
  - 3 – Mellemlag

# Hvordan gjorde vi det?



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- Testtunnel
- Industriel tunnel
- Mellemlag
- Beregningsværktøjer



A photograph of an industrial interior, likely a basement or utility room. The ceiling is filled with a complex network of large, corrugated metal ducts and pipes. A prominent blue pump or motor unit is mounted on one of the pipes. The floor is made of concrete, and there are some wooden beams and panels visible on the right side.

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## Resultater



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# Testresultater

## ■ Test matrice

<b>Introduction</b>	T1	Documentation of; air flow, heat transfer coefficient and pressure drop.
<b>Reference</b>	T2	Reference test to be able to compare time, temperature and energy consumption in subsequent test.
	T3	Three-step air flow control starting with low flow – Time dependent.
	T4	Three-step air flow control; high-low-high flow – Time dependent. (Based on conclusion from test 3)
<b>Adjusting the air flow</b>	T5	Air flow controlled by temperature -30°C on air from pallet 3.
	T6	Air flow controlled by temperature -32°C on air from pallet 3.
	T7a	
	T7b	
<b>Verification of reference test</b>	T7c	A new reference test established.
	T7d	
	T7e	
<b>Constant air flow</b>	T8a	Low air flow.
	T8b	Middle air flow.
	T9	Pallet 300 mm from the fan (Based on CFD).
	T10	Only two pallets.
<b>Air distribution</b>	T11a	Baffles (6.5 m <sup>3</sup> /s) (Based on CFD).
	T11b	Baffles (4.1 m <sup>3</sup> /s) (Based on CFD).
	T12	Baffles and pallets 300 mm from the fan.
	T13	High air flow.
<b>Neptun air spacer</b>	T14	Middle air flow.
	T15	Low air flow.
	T16	Maximum flow.
	T17	Flow back and forth.
	T18	Flow back and forth 2.
	T19	Reference test 1 (6.5 m <sup>3</sup> /s).
	T20	Reference test 2 (6.5 m <sup>3</sup> /s).
	T21	Reference test 3 (6.5 m <sup>3</sup> /s).
<b>Test at Claus Sørensen</b>	T22	Low air flow (38 Hz).
	T23	Neptun air spacer.
	T24	Middle air flow (43 Hz).
	T25	Nine pallets instead of ten.
	T26	Flow back and forth.



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## Resultater – Testtunnel



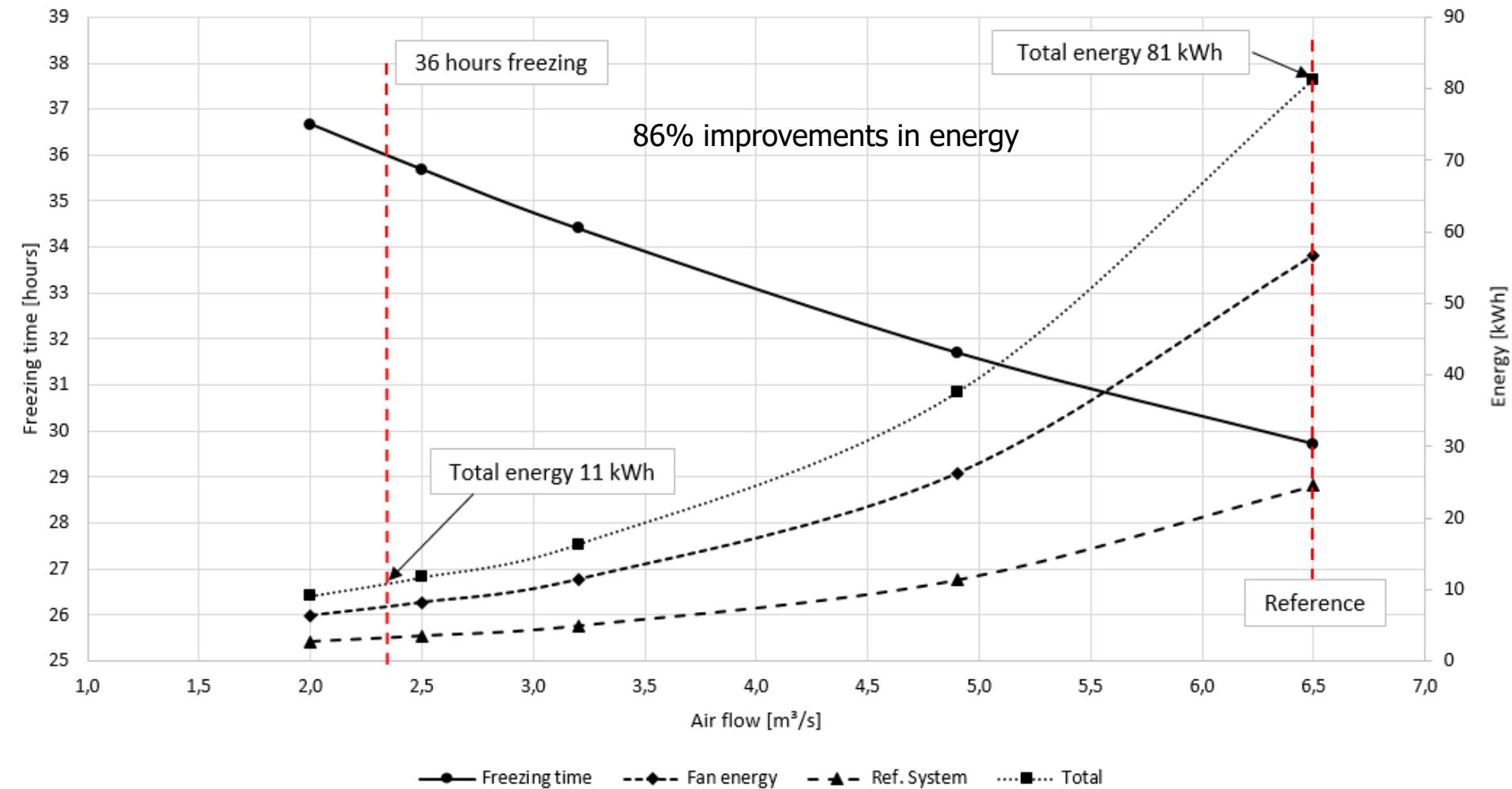
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# Luftflow



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Freezing time vs. air flow

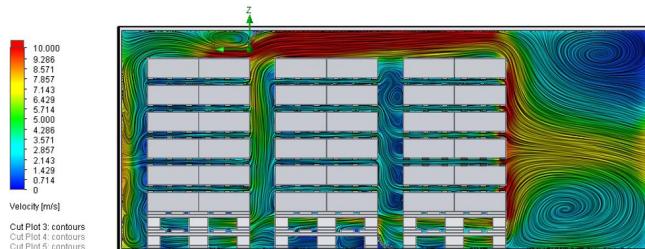


# Luftfordeling i tunneler

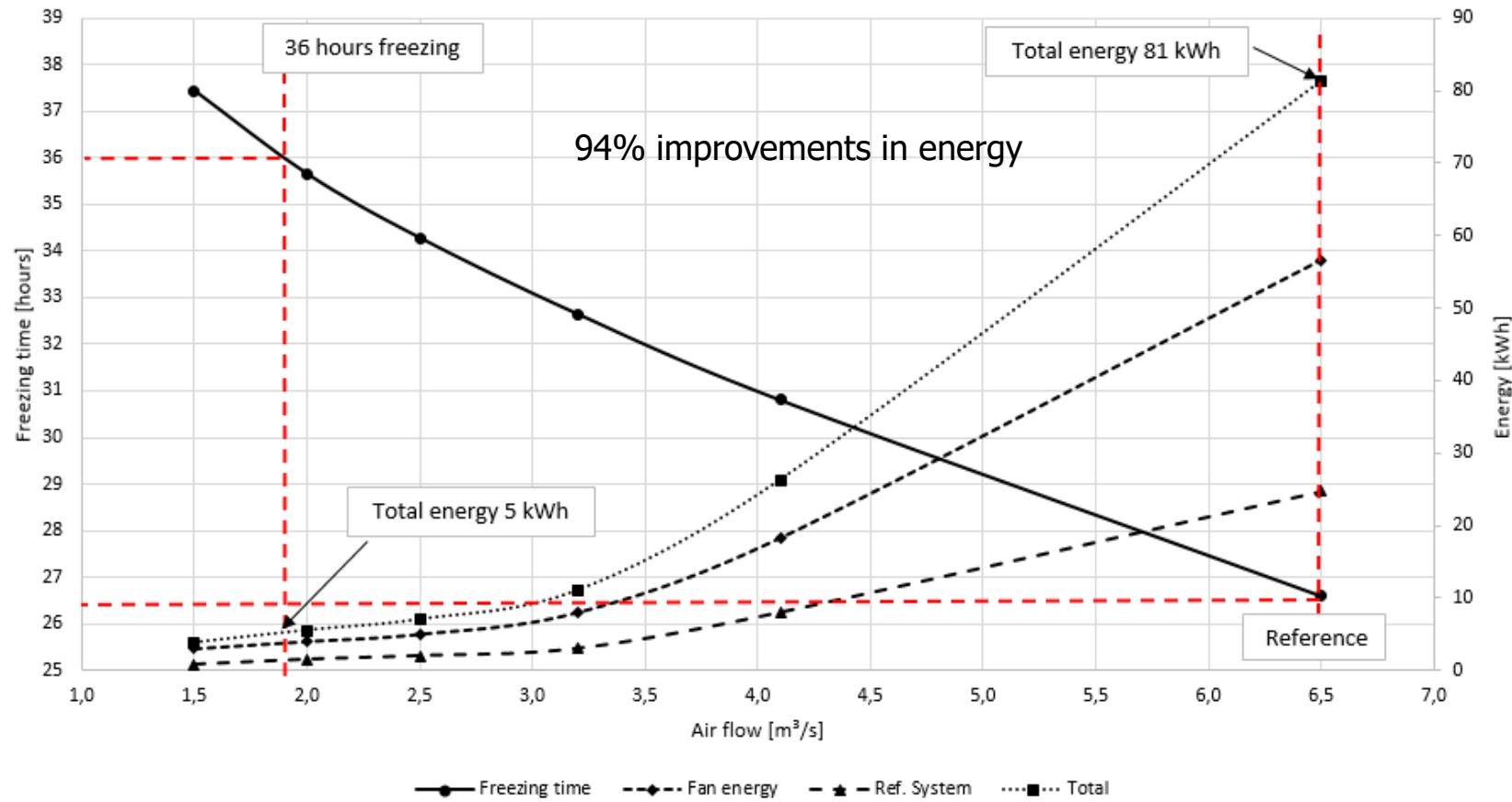


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## Baffler



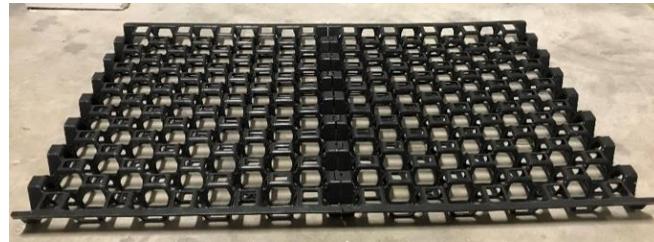
Freezing time vs. air flow with baffels



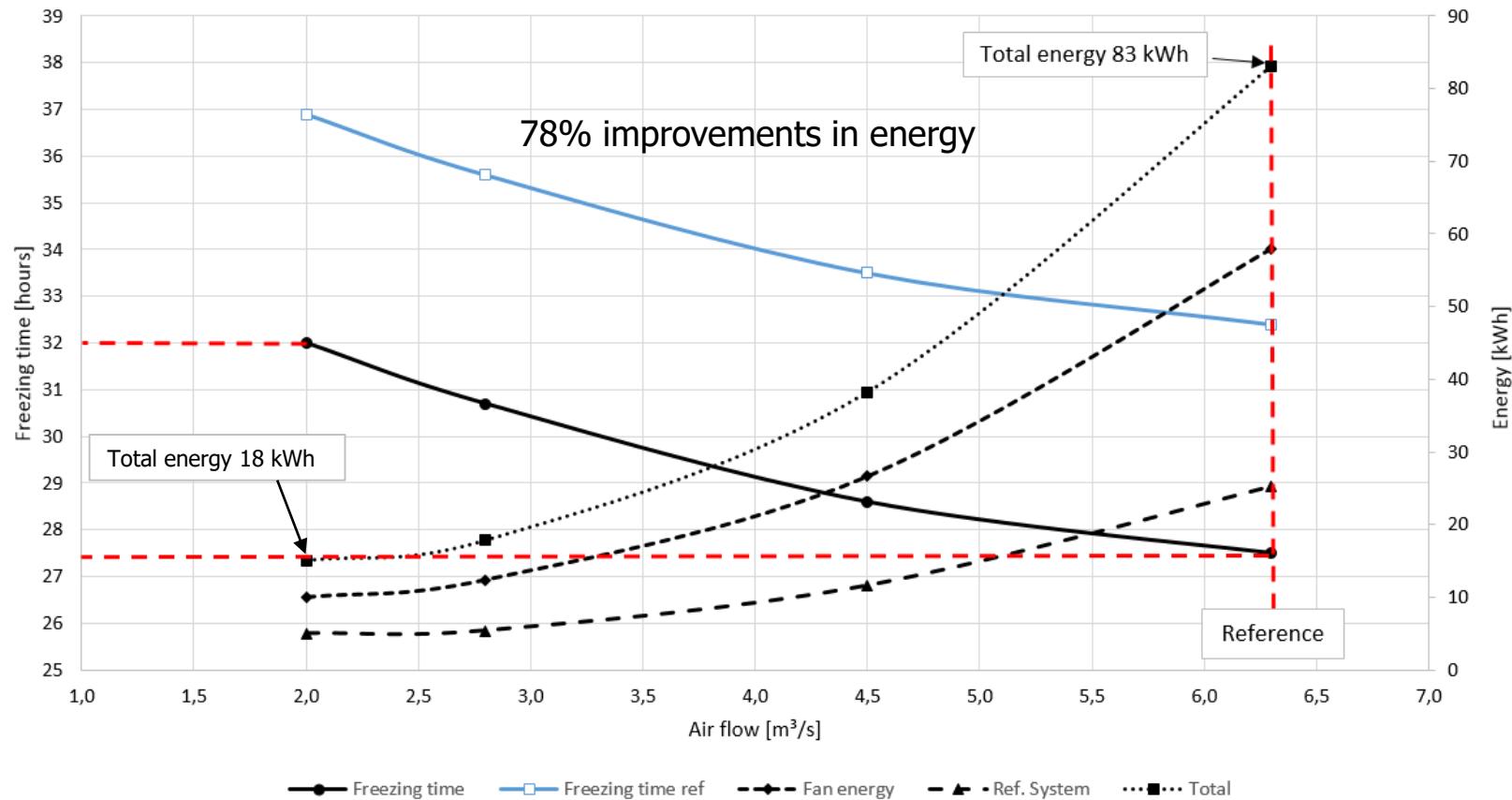
# Mellemlag



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Freezing time vs. air flow



A photograph showing the interior of an industrial tunnel. The ceiling and walls are made of large, corrugated metal sections. Various pipes, including blue and red ones, are visible running along the ceiling and walls. A large, dark cylindrical object, possibly a fan or鼓风机, is mounted on the ceiling. The floor appears to be concrete or a similar material.

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## Resultater – Industriel tunnel



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# Claus Sørensen - test



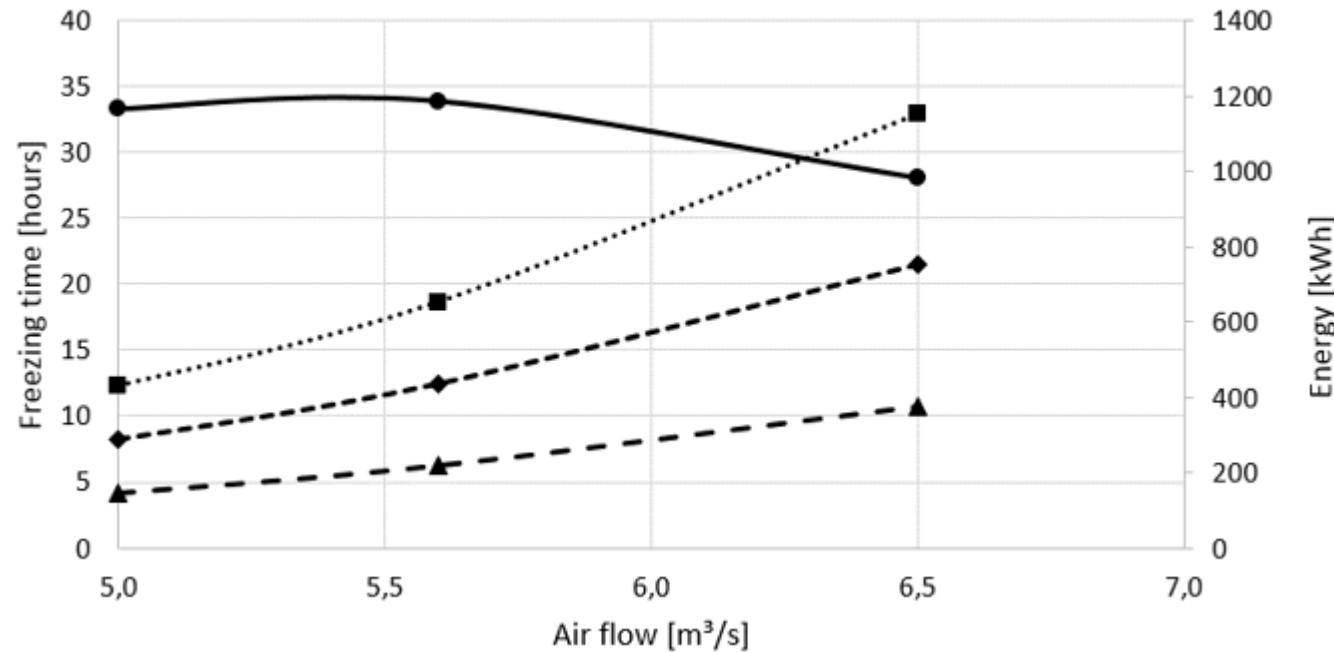
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## Test at Claus Sørensen

- T19 Reference test 1 ( $6.5 \text{ m}^3/\text{s}$ ).
- T20 Reference test 2 ( $6.5 \text{ m}^3/\text{s}$ ).
- T21 Reference test 3 ( $6.5 \text{ m}^3/\text{s}$ ).
- T22 Low air flow (38 Hz).
- T23 Neptun air spacer.
- T24 Middle air flow (43 Hz).
- T25 Nine pallets instead of ten.
- T26 Flow back and forth.

Freezing time vs. air flow



Test no.	Air flow [m³/s]	Freezing time		Energy usage						
		Total [h]	Improvements [h]	Fan [kWh]	Ref sys [kWh]	Total [kWh]	Improvements [%]			
Reference	T19-T21	6.5	28.0	0.0	0.0%	752.7	376.3	1129.0	0.0	0.0%
CS	T22	5.0	33.3	-5.3	-19%	286.8	143.4	430.2	698.9	61.9%
	T24	5.6	33.9	-5.9	-21%	435.0	217.5	652.5	476.5	42.2%



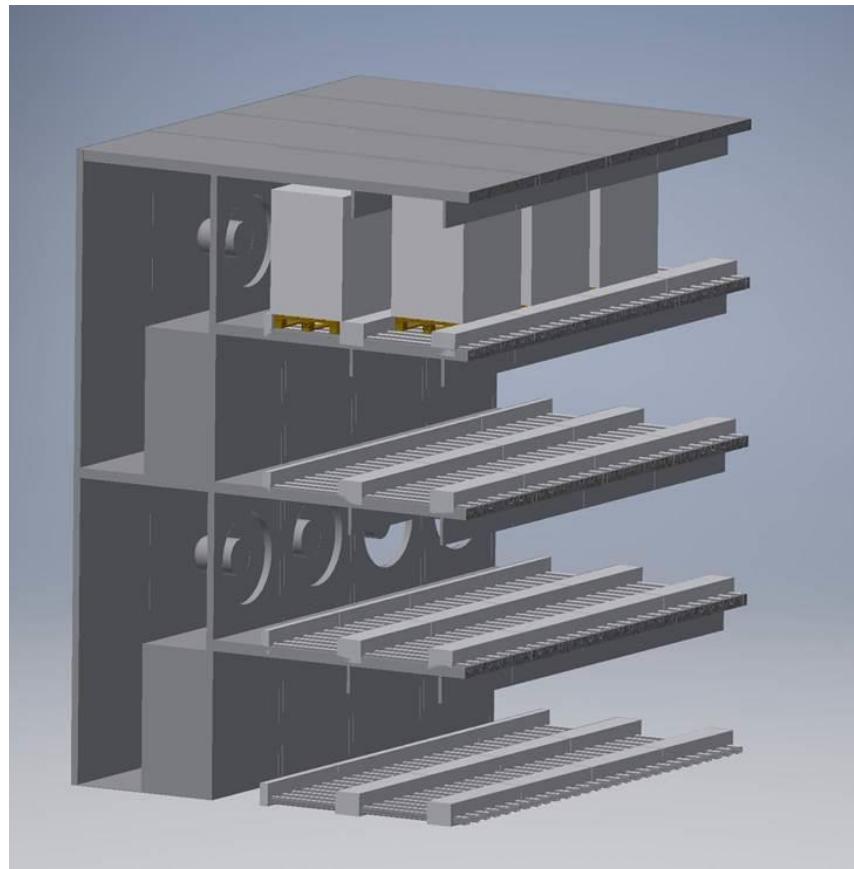
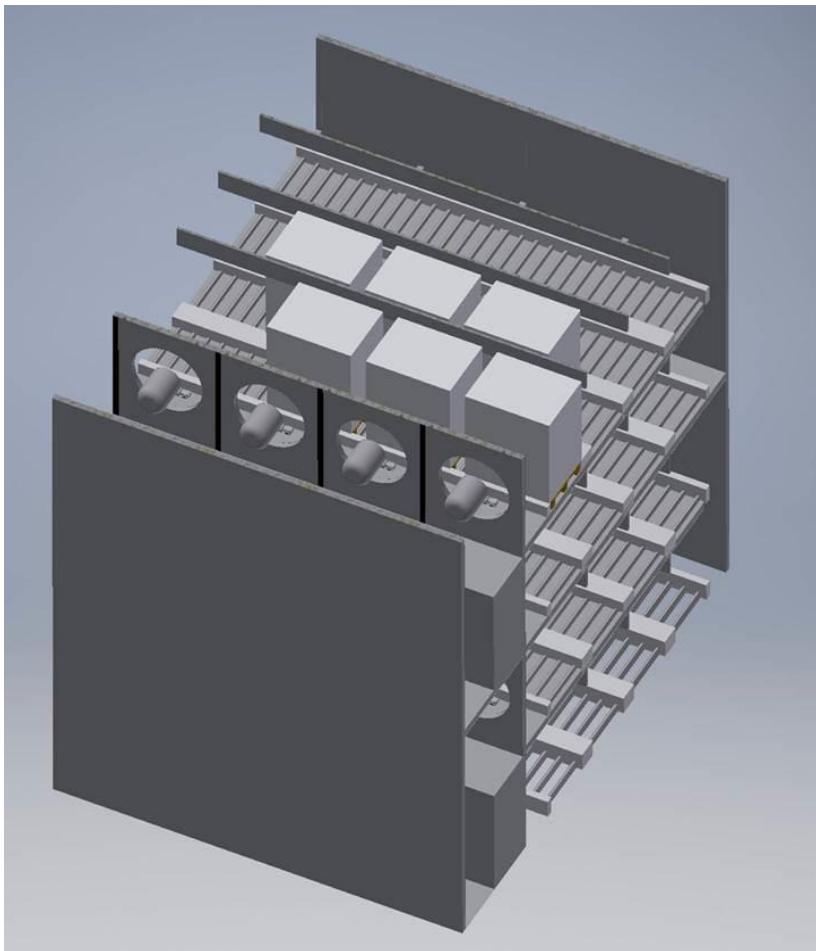
3

Ny karton tunnelindfryser



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# Nyt design fra Hørup Maskiner



A photograph of a complex industrial ceiling or ductwork system. It features a network of large, metallic pipes, some with insulation, and several blue and white rectangular ducts. The ceiling is supported by a grid of metal beams and brackets. A small, dark, cylindrical object hangs from one of the pipes.

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## Konklusioner



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# Konklusioner

- Stærkt reduceret energiforbrug fra 86% til 94%.
- Med meget simple tiltag.
- Nøglen er at sænke lufthastighed og udnytte cyklustiden.
- Claus Sørensen er ved at implementere resultaterne af projektet.
- Hørup Maskiner har udviklet ny karton tunnelfryser, som bygger på resultaterne af projektet.
- Energioptimering er vej til bedre bundlinje.

- Tak for opmærksomheden!



Rapporten kan hentes fra: <https://www.teknologisk.dk/soki/40080>



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# Test indfryser



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## The test tunnel freezer

- Scaled down version of the industrial freezer
- Used CFD to verify the down scaling
- $\text{CO}_2$  used as refrigerant
- 3 pallets and 1 row

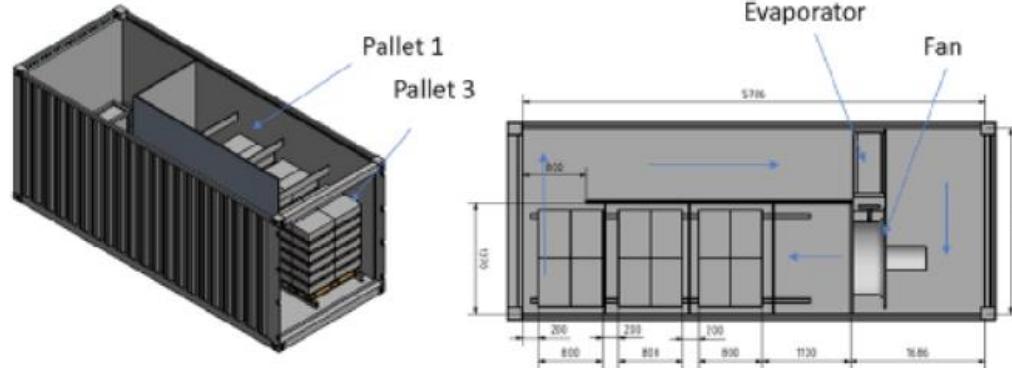


Figure 2: Test setup built into a container. Right - the layout seen from above.



Figure 3: Test container in laboratory



Figure 4: Evaporator coil and fan



Figure 5: The third product pallet and return air channel

# Industrial indfryser ved CS

## The industrial freezer

- Ammonia as refrigerant
- 20 pallets in each row
- 4 rows in height
- 80 pallets in total
- 30 tons of products
- Wooden freezing spacers
- Cycle time of the products investigated: 36 hours
- The site has 11 tunnels

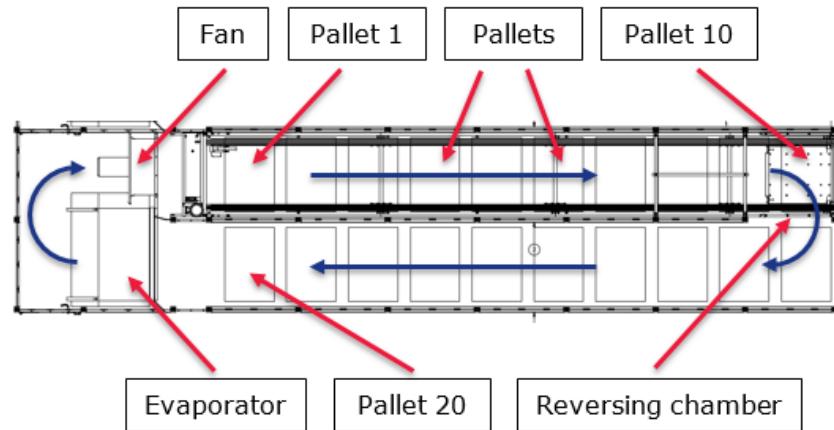


Figure 1: Freezer front view (left) and one row in the freezer seen from above (right).

# Mellemlag



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## The freezer spacers tested

- Wooden air spacer
- New Neptun freezer spacer NFS-II



## The simulated product pallet in the test tunnel

- Water in the boxes
- Box size  
600x400x150 mm
- 6 rows with freezer  
spacers in between  
placed on a Euro pallet

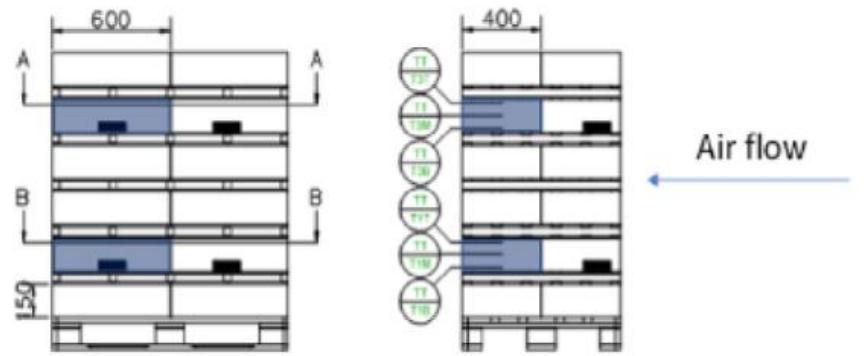
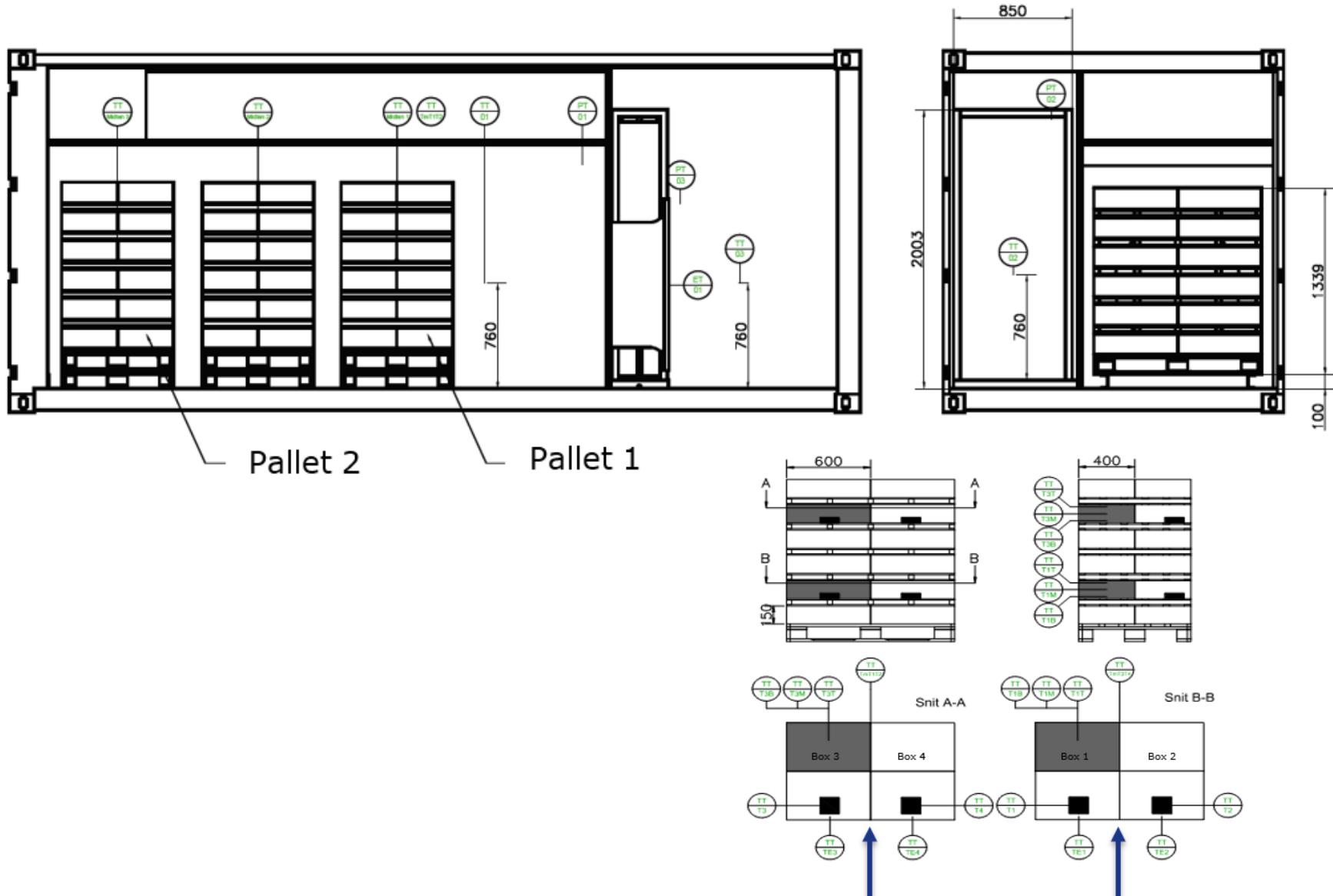


Figure 6: Shaded boxes represent the ones with temperature sensors at three levels

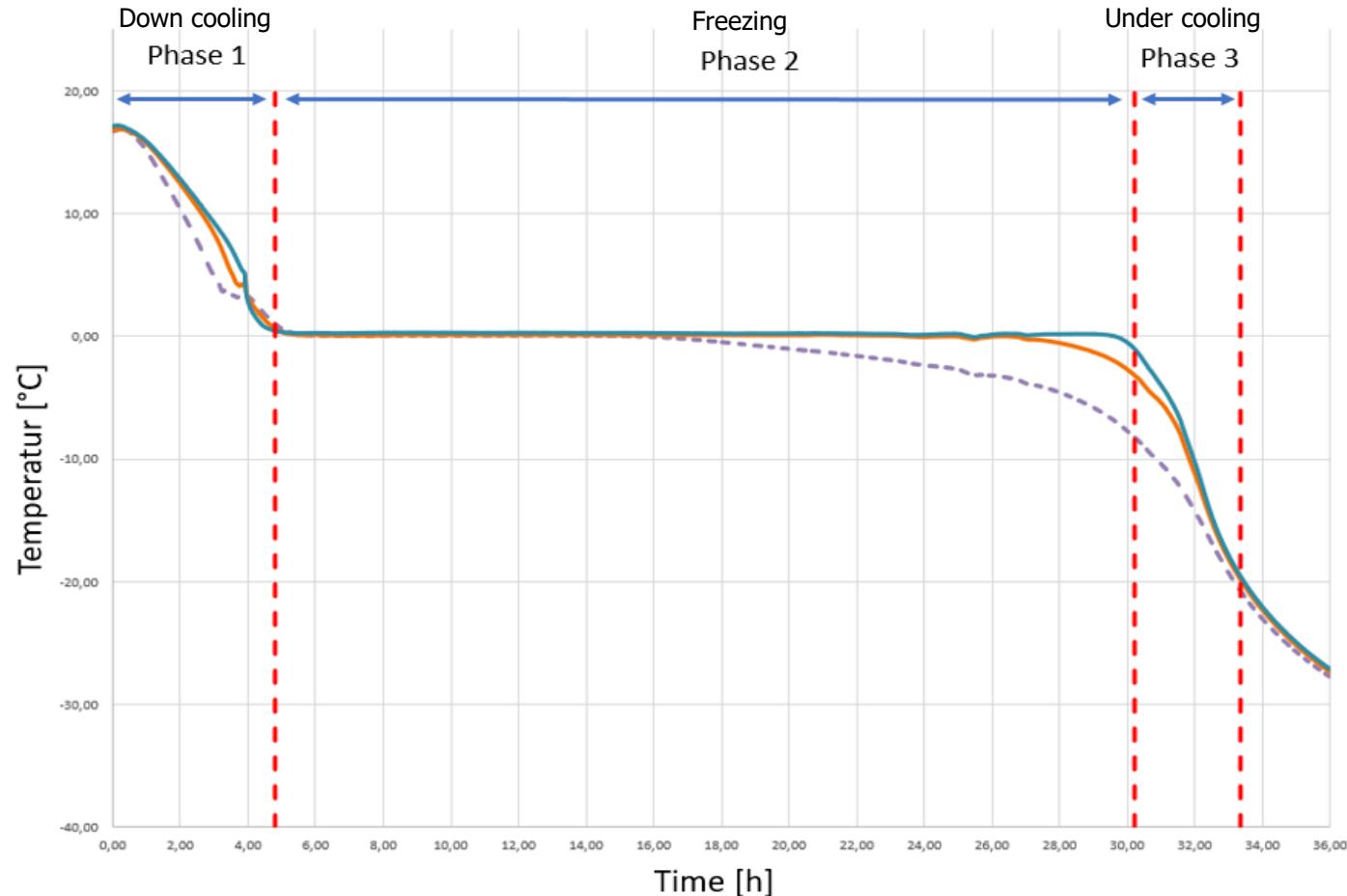
# Målinger i test tunnellen



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# Faserne i indfrysning



# Hvad styrer indfrysningen?

- Frysetiderne

$$\tau_{down\ cooling} = \rho \cdot c_p \cdot b \cdot l n \left( \frac{\frac{t_{start} - t_a}{t_{freezing} - t_a}}{\left( \frac{1}{h} + \sum \left( \frac{\delta}{k} \right)_{Packing} \right)} + \frac{b}{2 \cdot k_{unfrozen\ product}} \right)$$

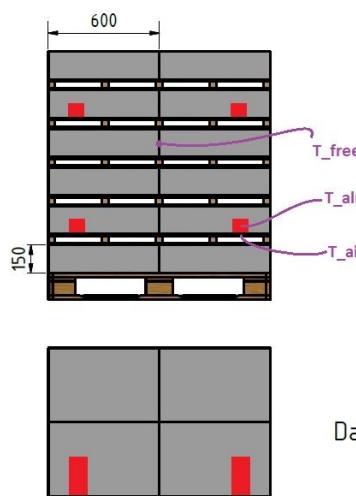
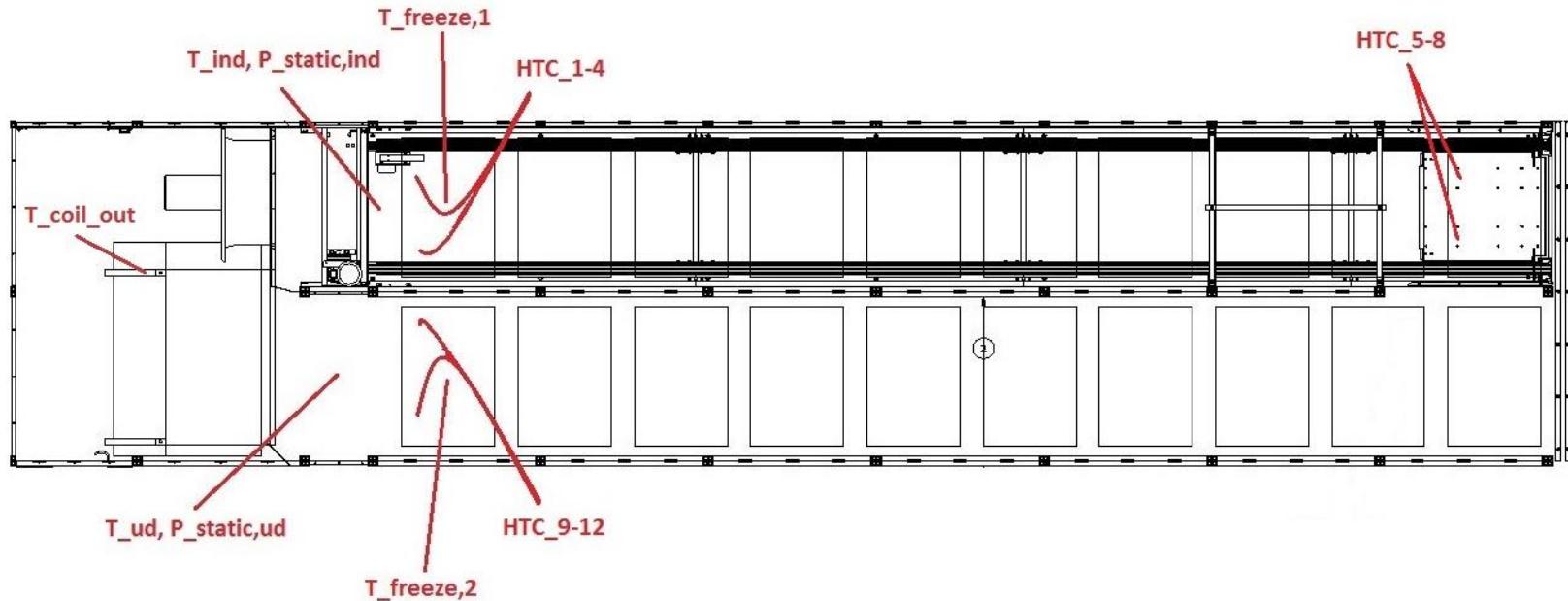
$$\tau_{freezing} = \frac{\Delta H_{vol}}{t_{freezing} - t_a} \left( \frac{1}{h} + \sum \left( \frac{\delta}{k} \right)_{Packing} + \frac{b}{2 \cdot k_{frozen\ product}} \right) \cdot b$$

$$\tau_{undercooling} = \rho \cdot c_p \cdot b \cdot l n \left( \frac{\frac{t_{start} - t_a}{t_{final} - t_a}}{\left( \frac{1}{h} + \sum \left( \frac{\delta}{k} \right)_{Packing} \right)} + \frac{b}{2 \cdot k_{frozen\ product}} \right)$$

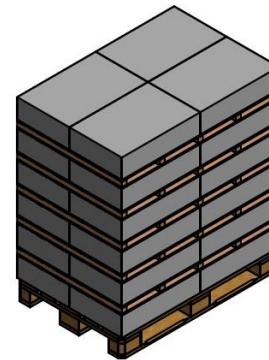
# Industrial indfryser ved CS



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Danish Crown Nakkefillet 600x400x150

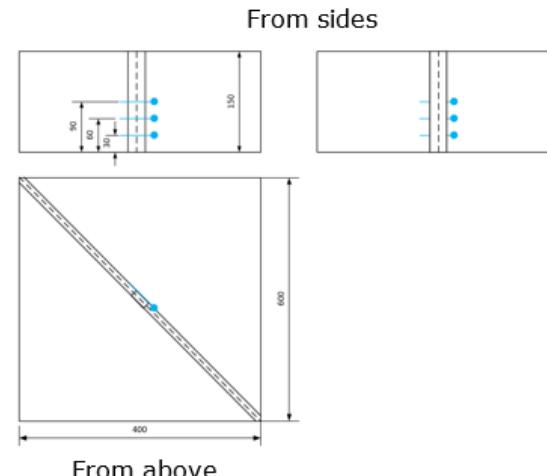


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# Målinger inde i kasserne



**Figure 8: The construction of the measuring pallet. From the left: Water bags ready for water with thermocouples, in the middle in three different levels, finished water bag, and finally a frozen water bag.**

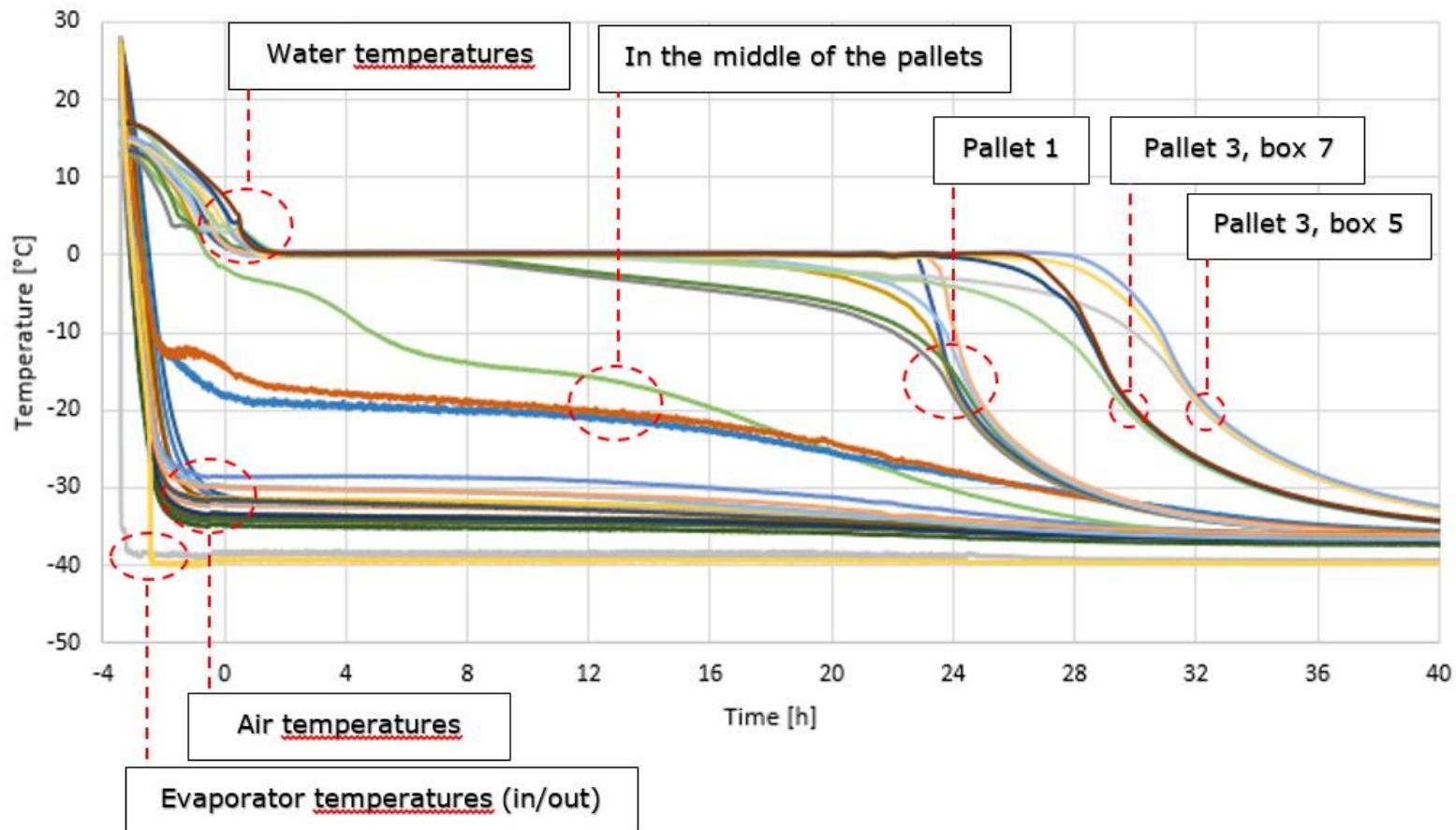


**Figure 10: Graphic illustration of the exact location of each temperature measurement in the measurement boxes.**

# Eksempel af målinger



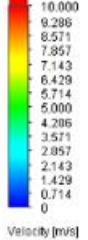
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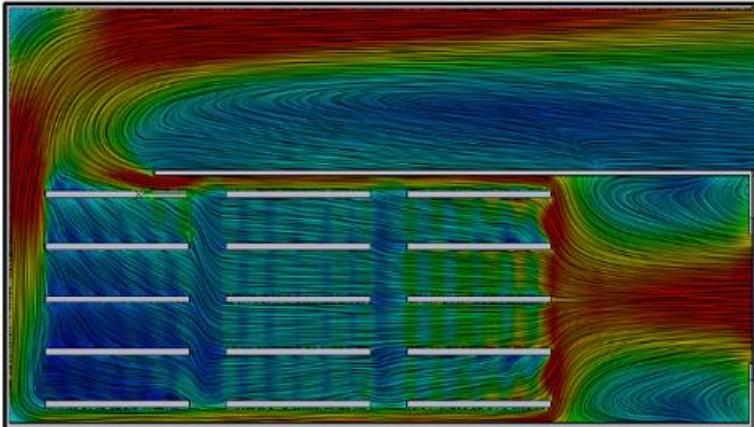
# CFD – reference kørsel



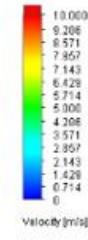
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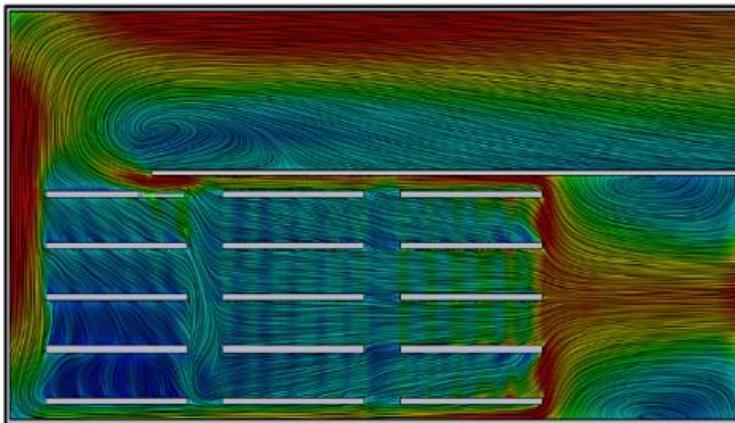
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Cut Plot 6: contours



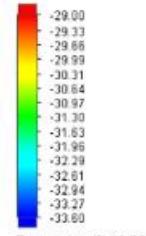
Lavt snit



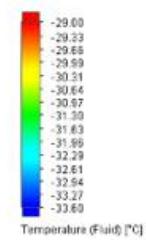
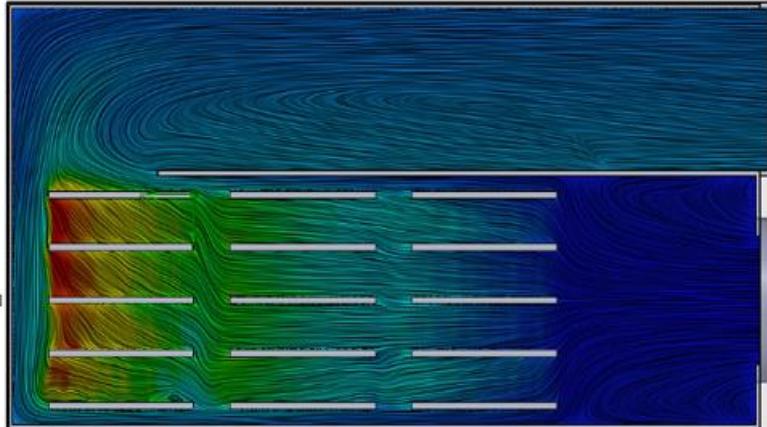
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Cut Plot 8: contours



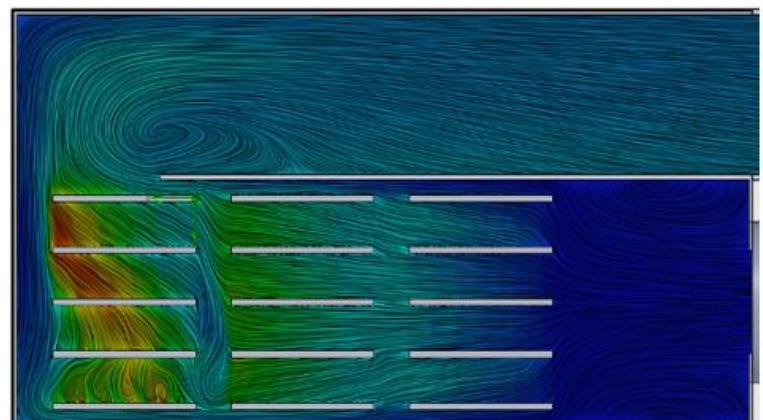
Højt snit



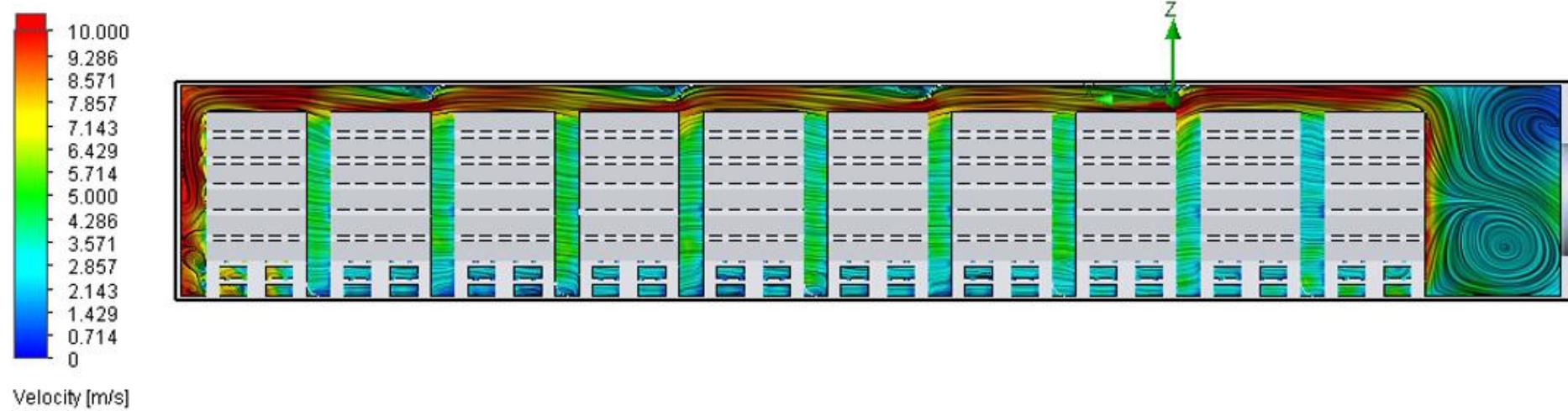
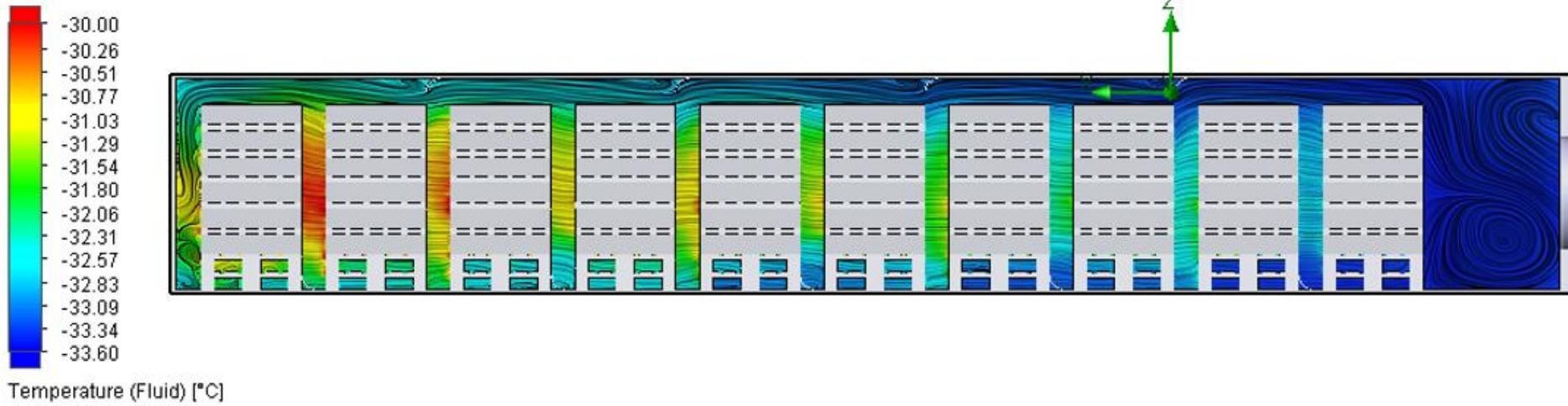
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Cut Plot 3: contours  
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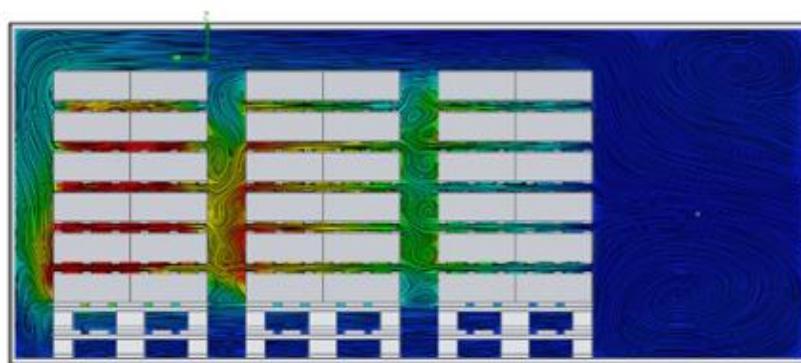
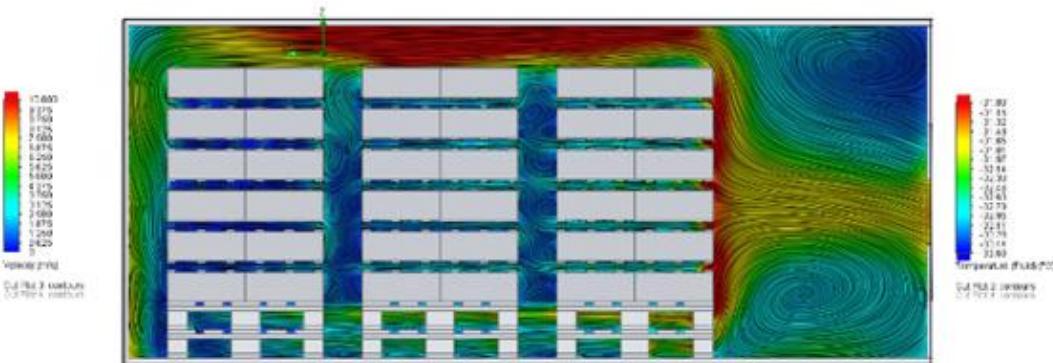


# CFD – Baffler – Industrial tunnel



# CFD – Reference kørsel

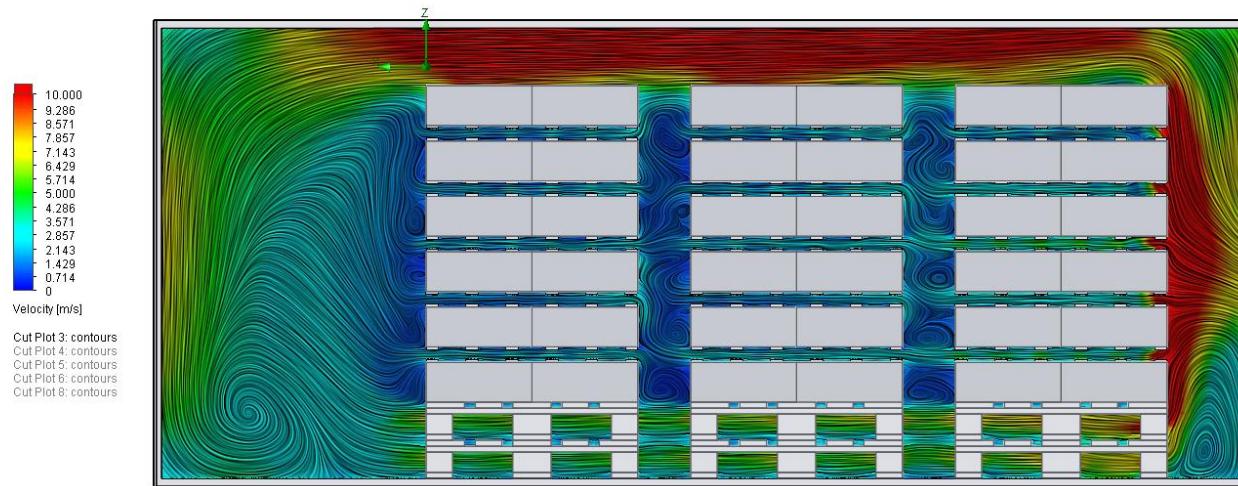
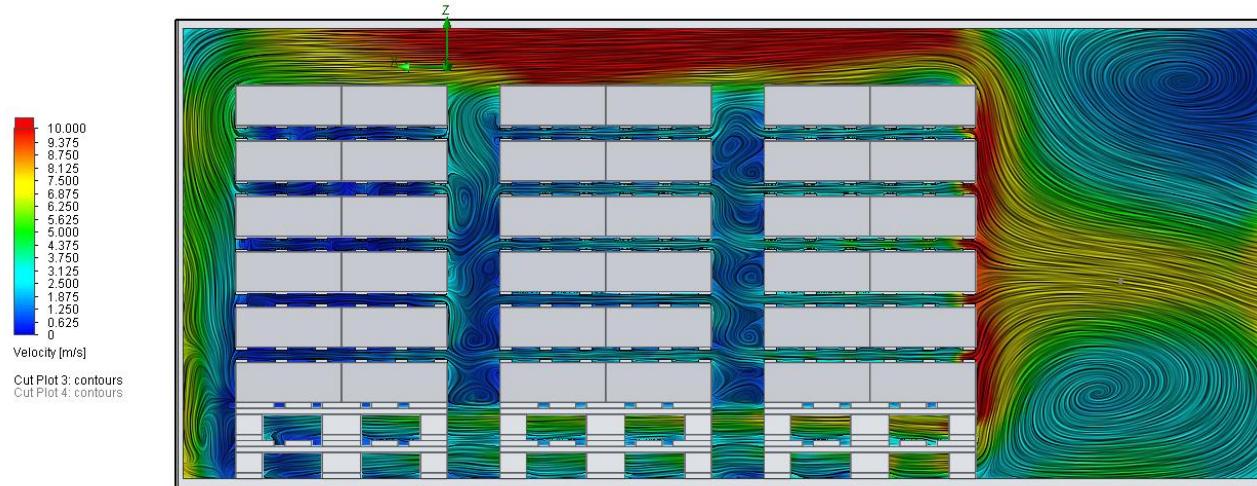
- Reference kørsel



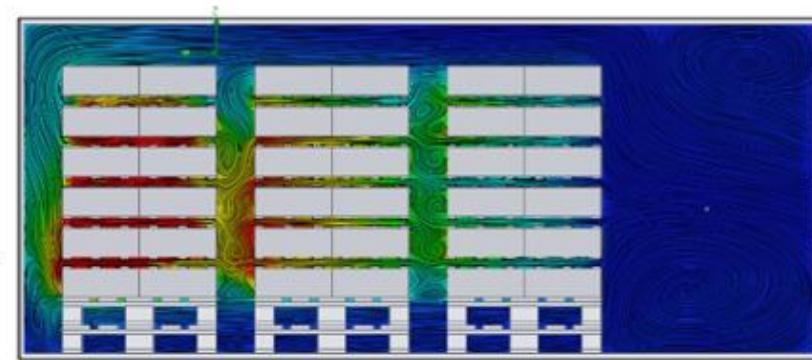
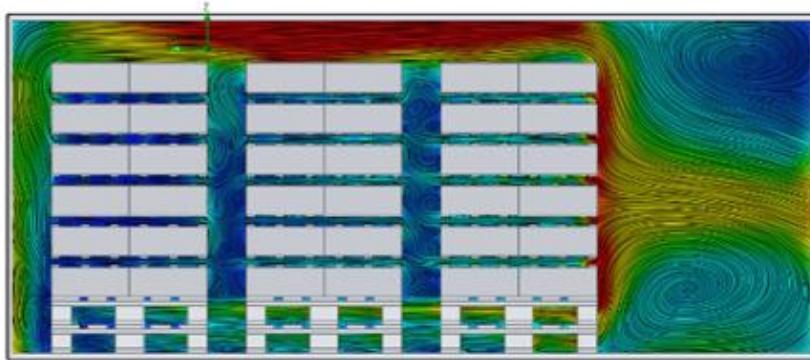
# CFD – Paller flyttet



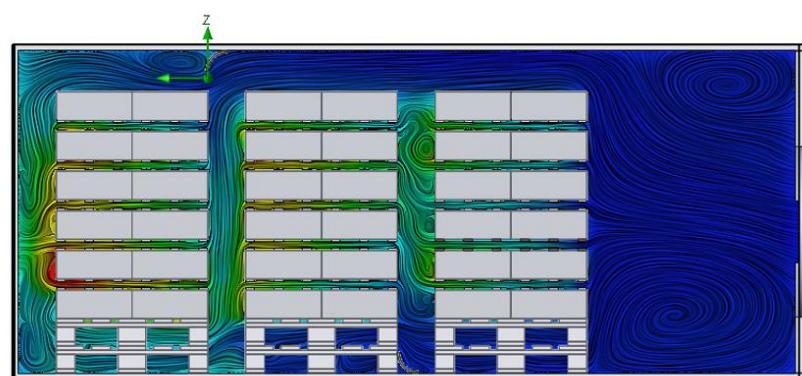
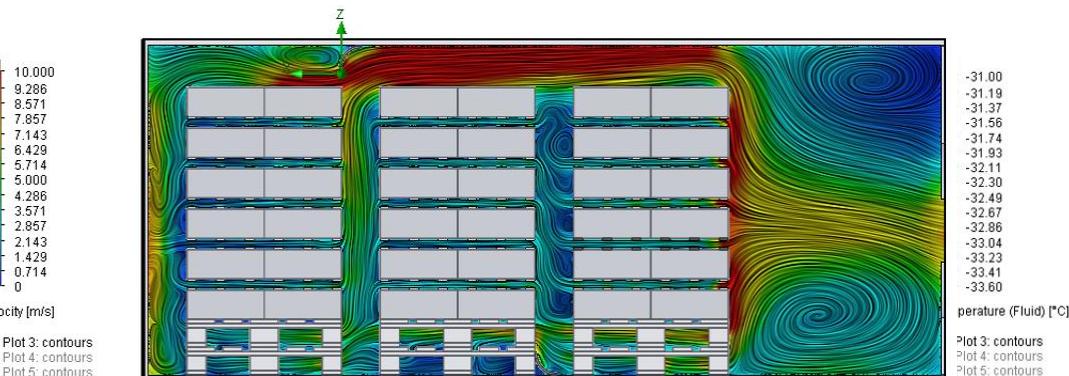
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# CFD – Baffler

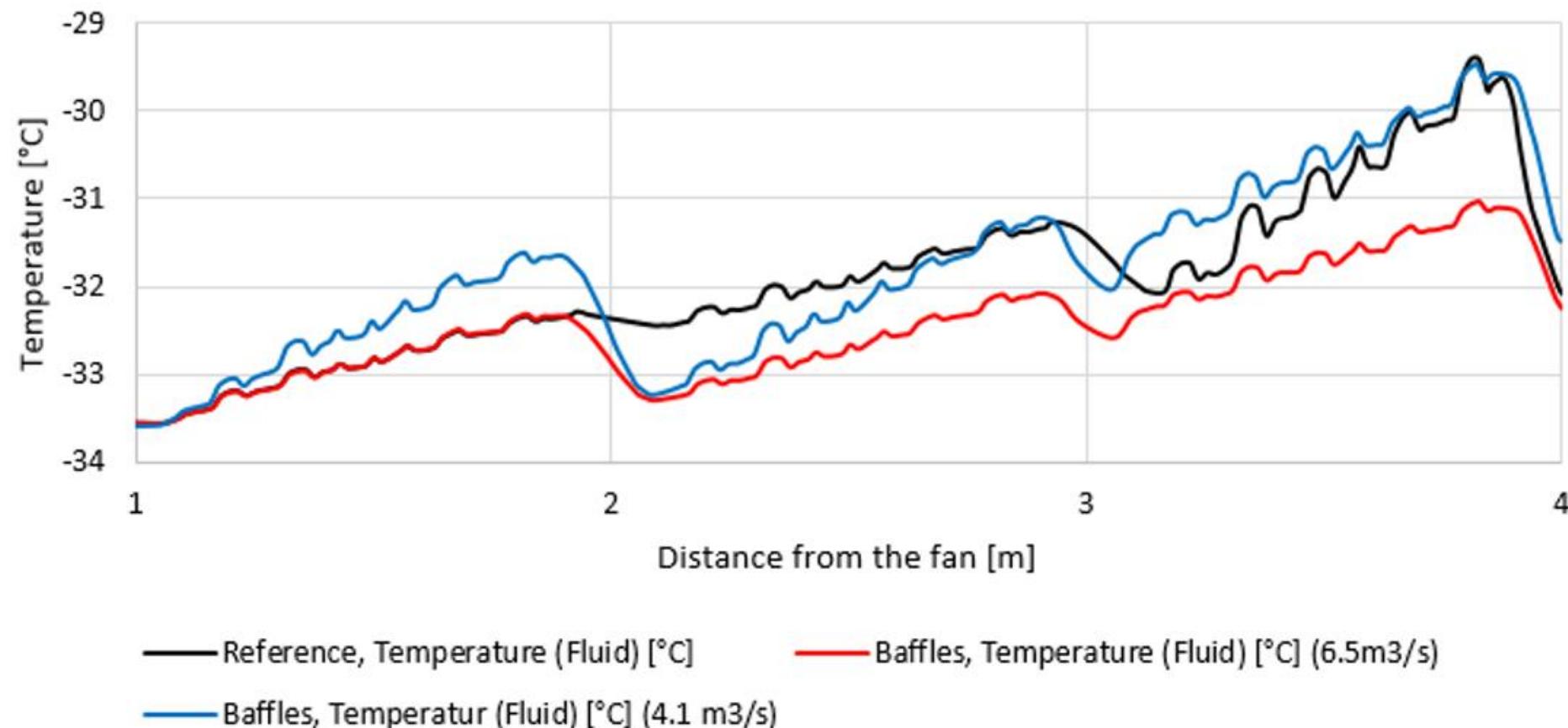


## Referencen



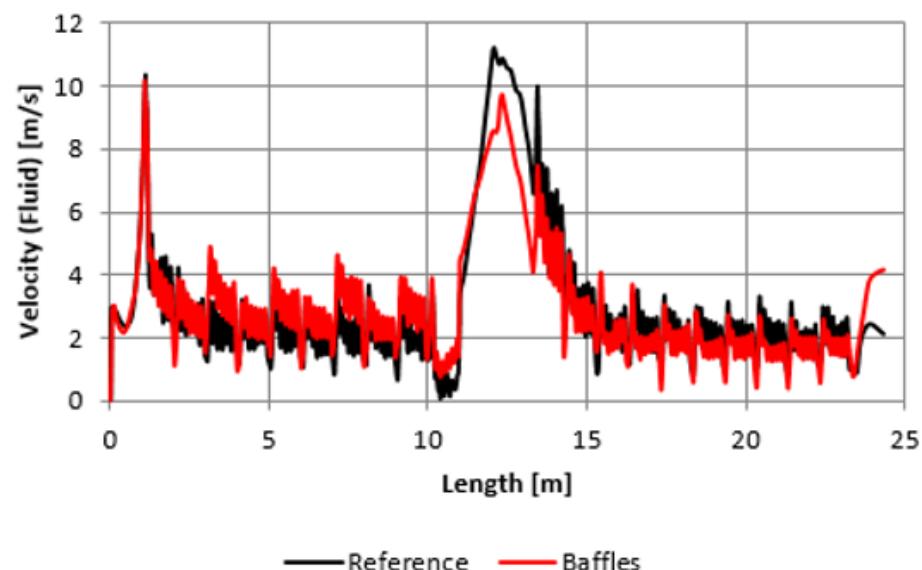
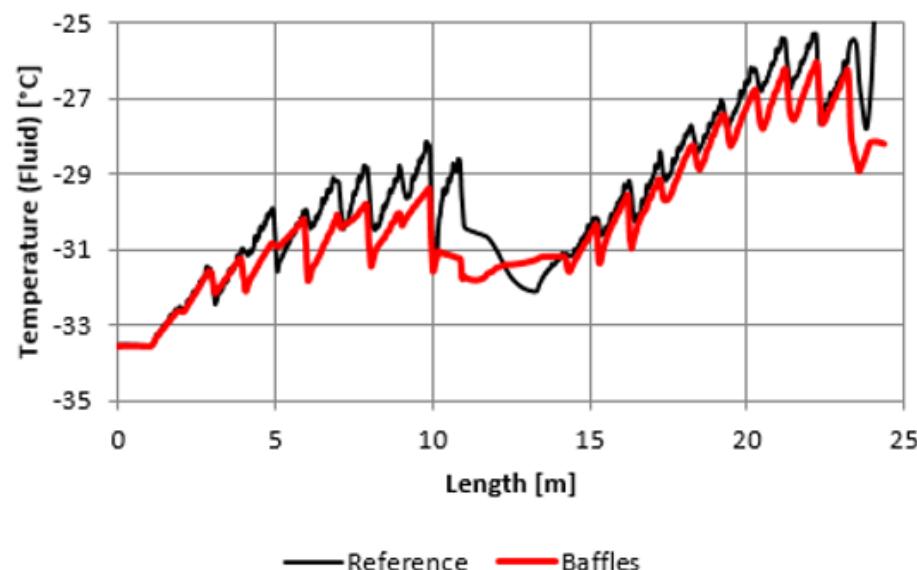
## Baffler

# CFD – Baffler



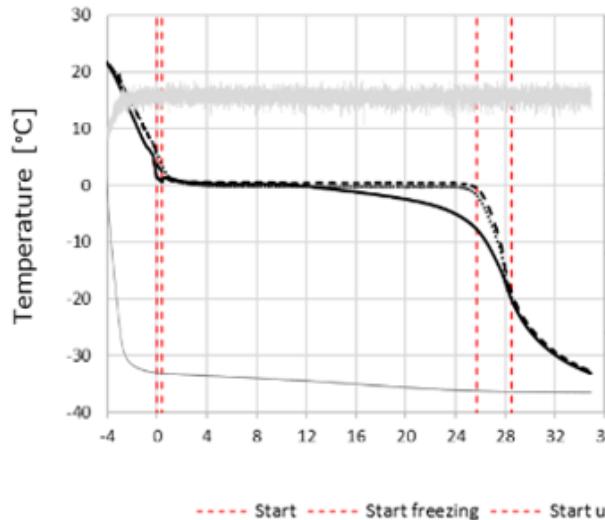
# CFD – Baffler – Industrial tunnel

- Temperatur og hastighedsforløb

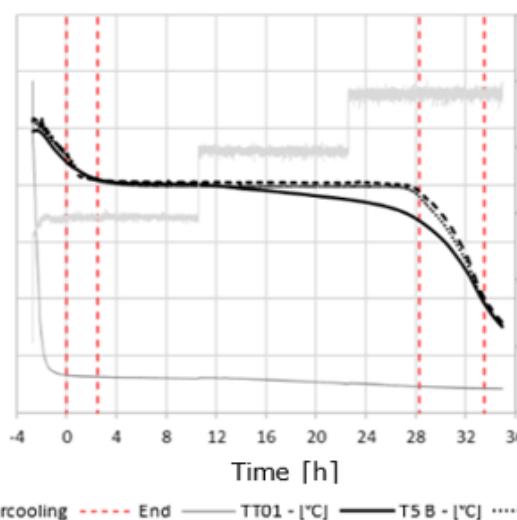


# Varierende luft flow

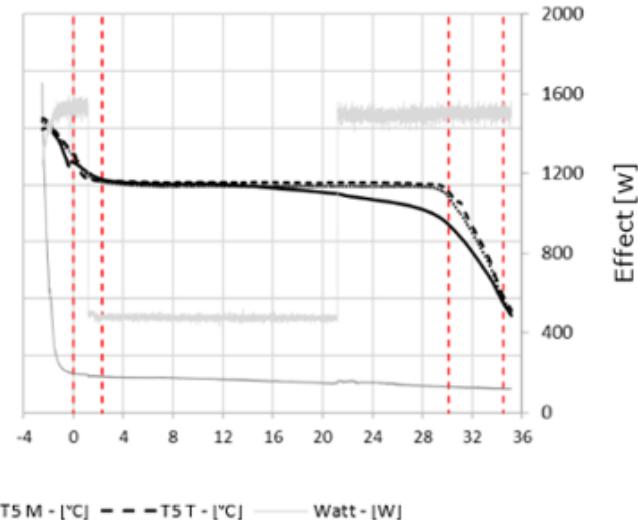
Reference test



Test T3



Test T4

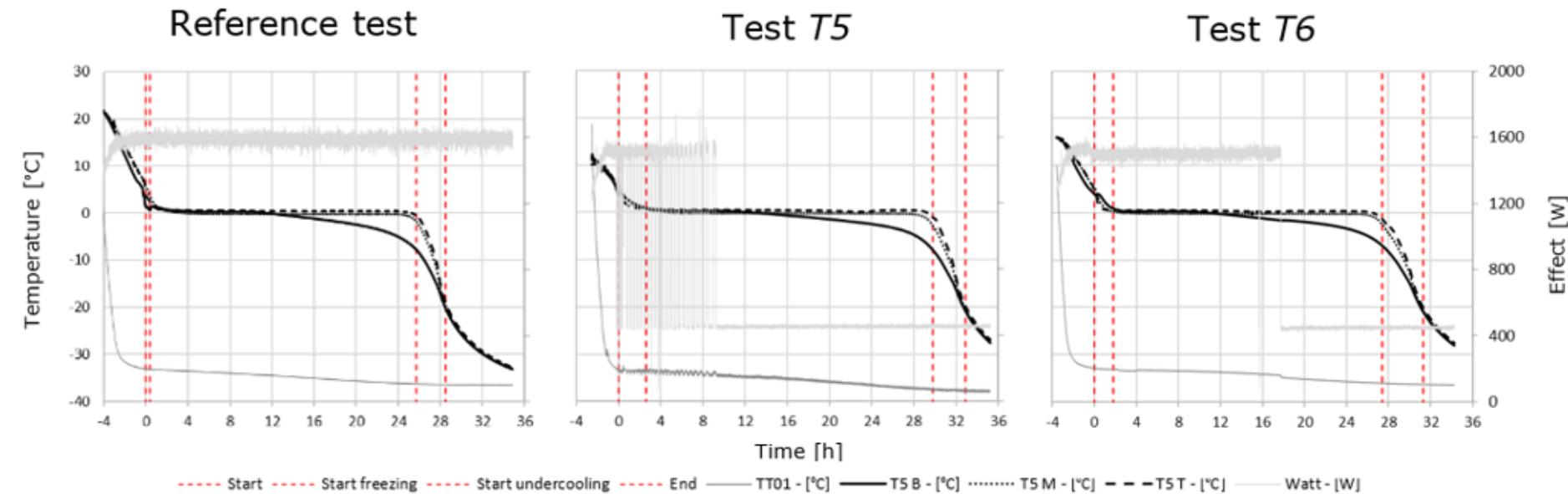


Test no.	Air flow [m³/s]	Freezing time			Energy usage					
		Total [h]	Improvements [h]	[%]	Fan [kWh]	Ref sys [kWh]	Total [kWh]	Improvements [kWh]	[%]	
		T7a - T7e	29.8	0.0	0.0%	56.7	24.7	81.4	0.0	0.0%
Reference										
Fan control.	T3	4.2/5.0/6.5	33.5	-3.7	-12.6%	42.8	18.6	61.4	19.9	24.5%
Variable flow	T4	6.5/4.0/6.5	34.5	-4.7	-15.9%	33.6	14.6	48.2	33.1	40.7%

# Varierende luft flow



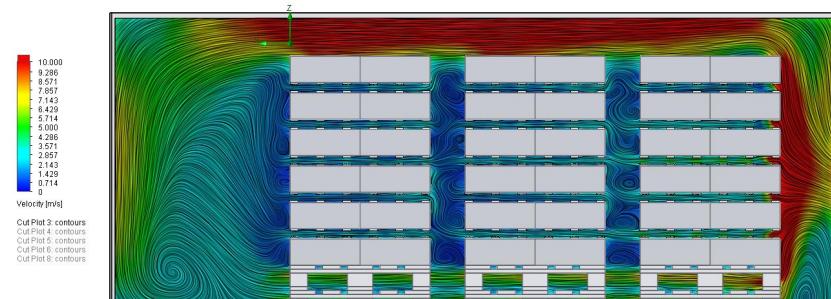
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Test no.	Air flow		Freezing time		Energy usage					
			Total	Improvements	Fan	Ref sys	Total	Improvements		
	[m³/s]	[h]	[h]	[%]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	
Reference	T7a - T7e	6.5	29.8	0.0	0.0%	56.7	24.7	81.4	0.0	0.0%
Fan control.	T5	6.5/4.2	32.8	-3.0	-10.2%	22.7	9.9	32.6	48.8	60.0%
Variable flow	T6	6.5/3.95	31.1	-1.3	-4.5%	34.7	15.1	49.8	31.6	38.8%

# Luft fordeling

- Paller tættere på blæser T9 og to paller i luftretning T10

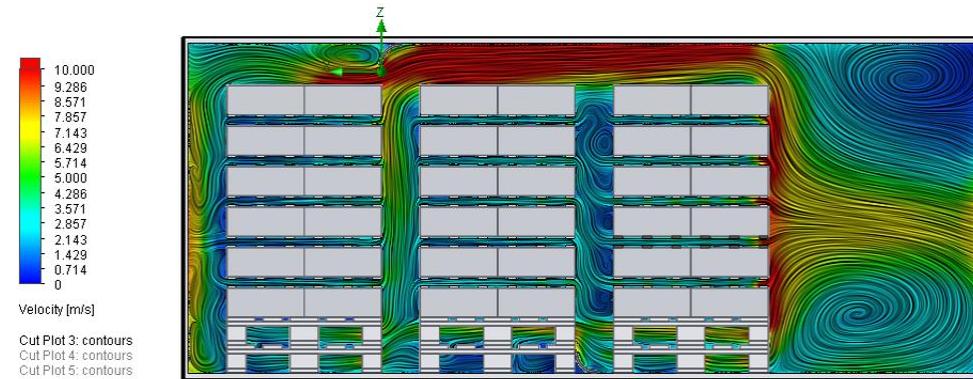


T9 – Paller tættere på blæser

Test no.	Air flow [m <sup>3</sup> /s]	Freezing time			Energy usage					
		Total [h]	Improvements [h]	[%]	Fan [kWh]	Ref sys [kWh]	Total [kWh]	Improvements [kWh]	[%]	
Reference	<b>T7a - T7e</b>	6.5	29.8	0.0	0.0%	56.7	24.7	81.4	0.0	0.0%
Air	<b>T9</b>	6.5	26.8	3.0	9.9%	57.8	25.1	82.9	-1.6	-1.9%
	<b>T10</b>	6.5	24.4	5.4	18.0%	57.5	25.0	82.5	-1.1	-1.4%

# Luft fordeling i tunnelen

## ■ Baffler



Test no.		Air flow		Freezing time		Energy usage					
		Total	[m <sup>3</sup> /s]	Total	[h]	Improvements	[%]	Fan	Ref sys	Total	Improvements
		[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]
Reference	<b>T7a - T7e</b>	6.5		29.8	0.0	0.0%		56.7	24.7	81.4	0.0
Air	<b>T11</b>	6.5		26.6	3.2	10.6%		56.6	24.6	81.2	0.1
	<b>T11b</b>	4.1		30.8	-1.0	-3.5%		18.3	8.0	26.3	55.1

# Luft fordeling

- Baffler plus at flytte pallestak

Test no.		Air flow		Freezing time			Energy usage			
		Total	Improvements	Fan	Ref sys	Total	Improvements			
		[m³/s]	[h]	[h]	[%]	[kWh]	[kWh]	[kWh]	[kWh]	[%]
Reference	<b>T7a - T7e</b>	6.5	29.8	0.0	0.0%	56.7	24.7	81.4	0.0	0.0%
Air	<b>T12</b>	6.5	30.1	-0.3	-1.1%	53.1	23.1	76.2	5.2	6.3%

# Neptun mellemlag

- Besparelse i forhold til træ mellemlag



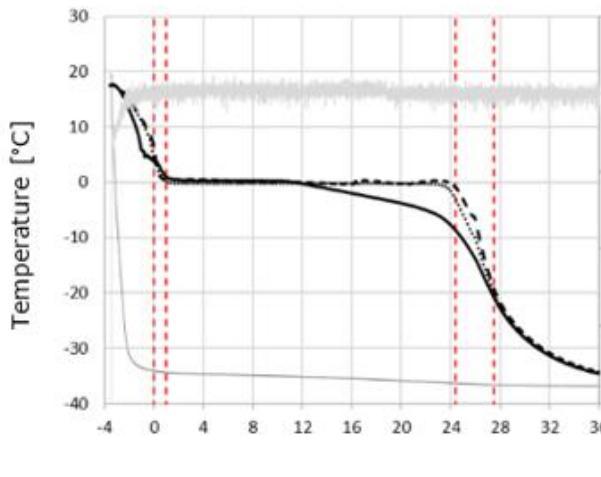
Test no.		Air flow		Freezing time			Energy usage				
		Total	[m³/s]	Total	[h]	Improvements	[%]	Fan	Ref sys	Total	Improvements
		[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[%]	
Reference	T2	6.5		32.4	0.0	0.0%		57.2	24.9	82.1	0.0
Neptun	T13	6.3		27.5	4.9	16.5%		57.9	25.2	83.1	-1.0

# Luft flow frem og tilbage

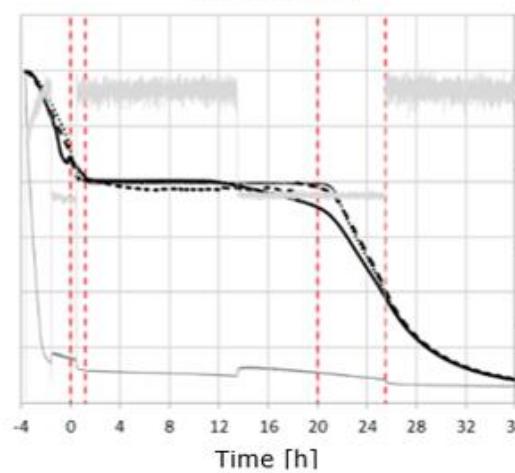


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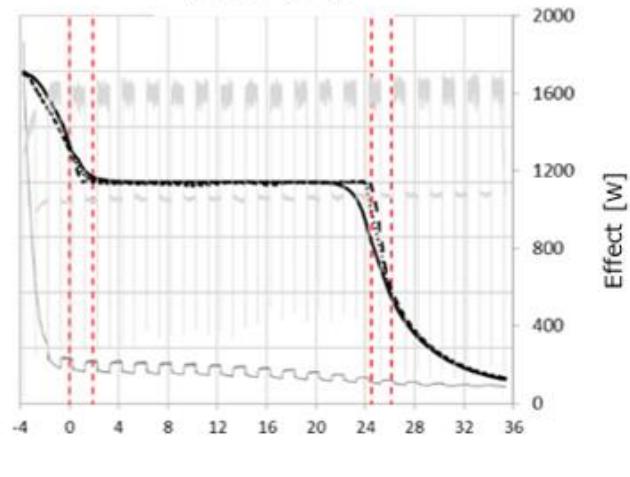
Test T13



Test T17



Test T18



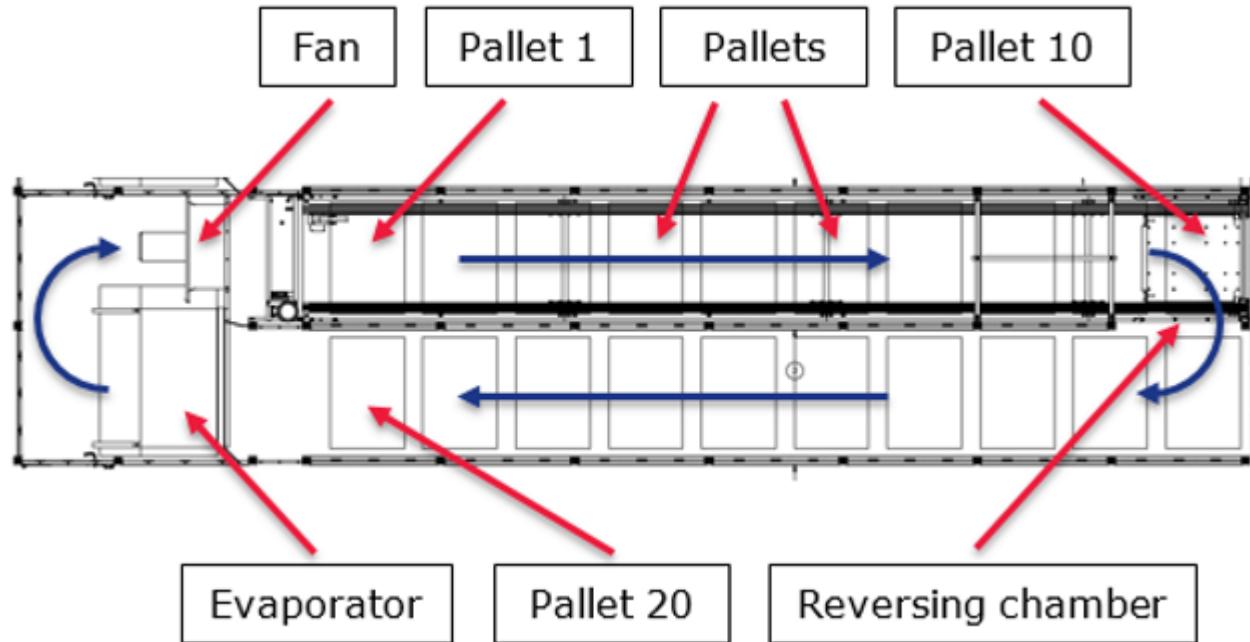
----- Start ----- Start freezing ----- Start undercooling ----- End — TT01 - [°C] — T5 B - [°C] ..... T5 M - [°C] --- T5 T - [°C] — Watt - [W]

Test no.		Air flow [m³/s]	Freezing time		Energy usage					
			Total [h]	Improvements [%]	Fan [kWh]	Ref sys [kWh]	Total [kWh]	Improvements [%]		
Reference	T13	6.3	27.5	0.0	0.0%	57.9	25.2	83.1	0.0	0.0%
Neptun	T17	6.2	25.6	1.9	7%	51.4	22.3	73.7	9.3	11%
	T18	6	26.1	1.4	5%	47.2	20.5	67.7	15.4	18%

# Luft flow frem og tilbage

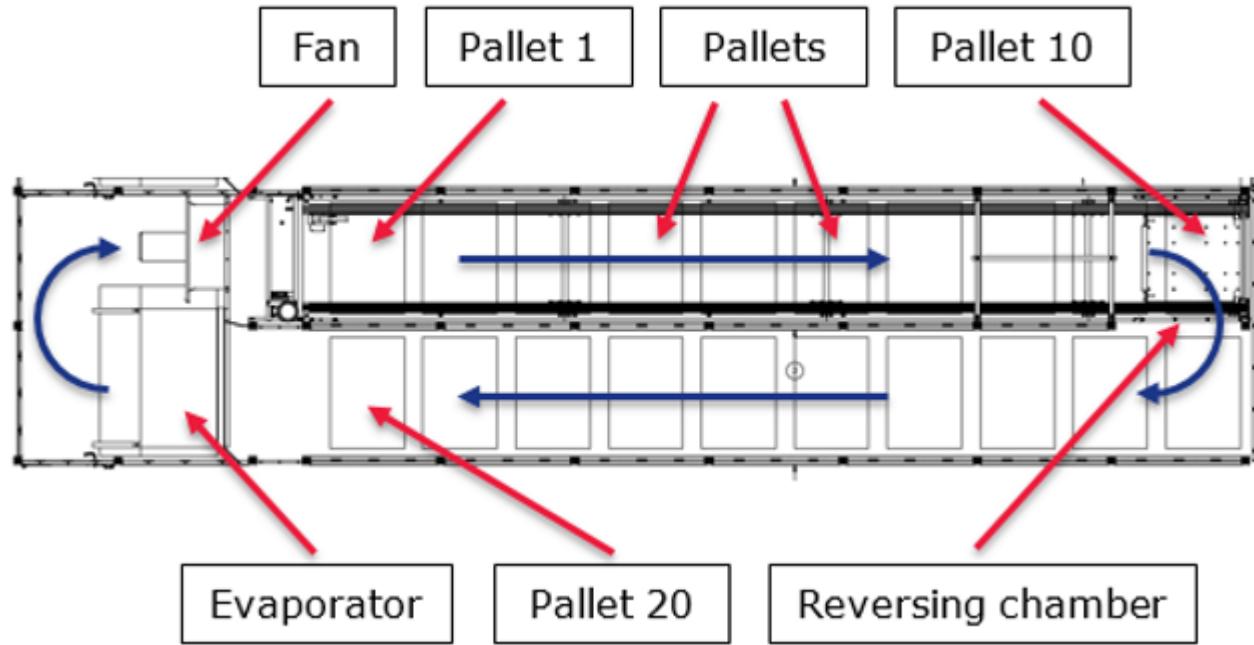


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Test no.		Air flow		Freezing time			Energy usage			
		[m <sup>3</sup> /s]	[h]	Total	Improvements	Fan	Ref sys	Total	Improvements	
				[h]	[%]	[kWh]	[kWh]	[kWh]	[%]	
Reference	<b>T19-T21</b>	6.5	28.0	0.0	0.0%	752.7	376.3	1129.0	0.0	0.0%
CS	<b>T26</b>	6.5	26.4	1.6	6%	676.0	338.0	1014.0	115.0	10.2%

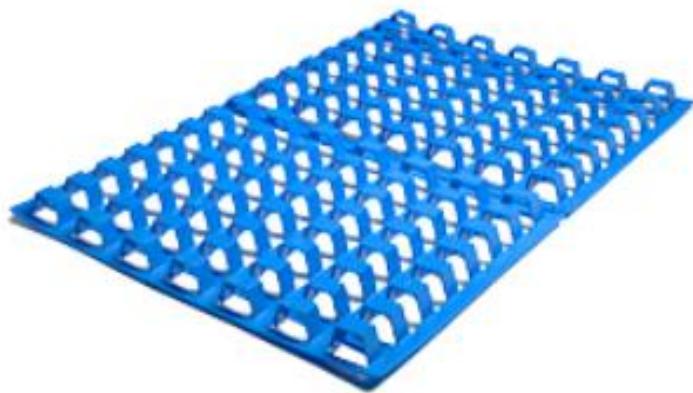
# 9 paller i stedet for 10



Test no.		Air flow [m <sup>3</sup> /s]	Freezing time			Energy usage			
			Total [h]	Improvements [h]	%	Fan [kWh]	Ref sys [kWh]	Total [kWh]	Improvements [kWh]
			0.0	0.0%		752.7	376.3	1129.0	0.0
Reference	T19-T21	6.5	28.0	0.0	0.0%	752.7	376.3	1129.0	0.0
CS	T25	6.5	28.7	-0.7	-3%	753.0	376.5	1129.5	-0.5

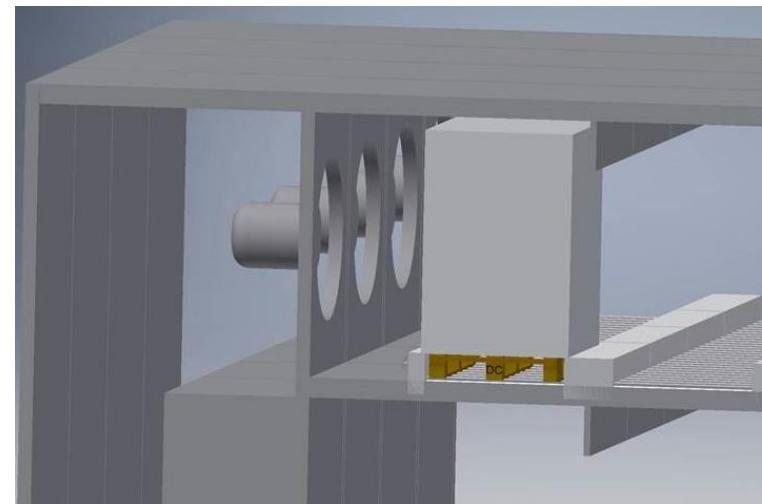
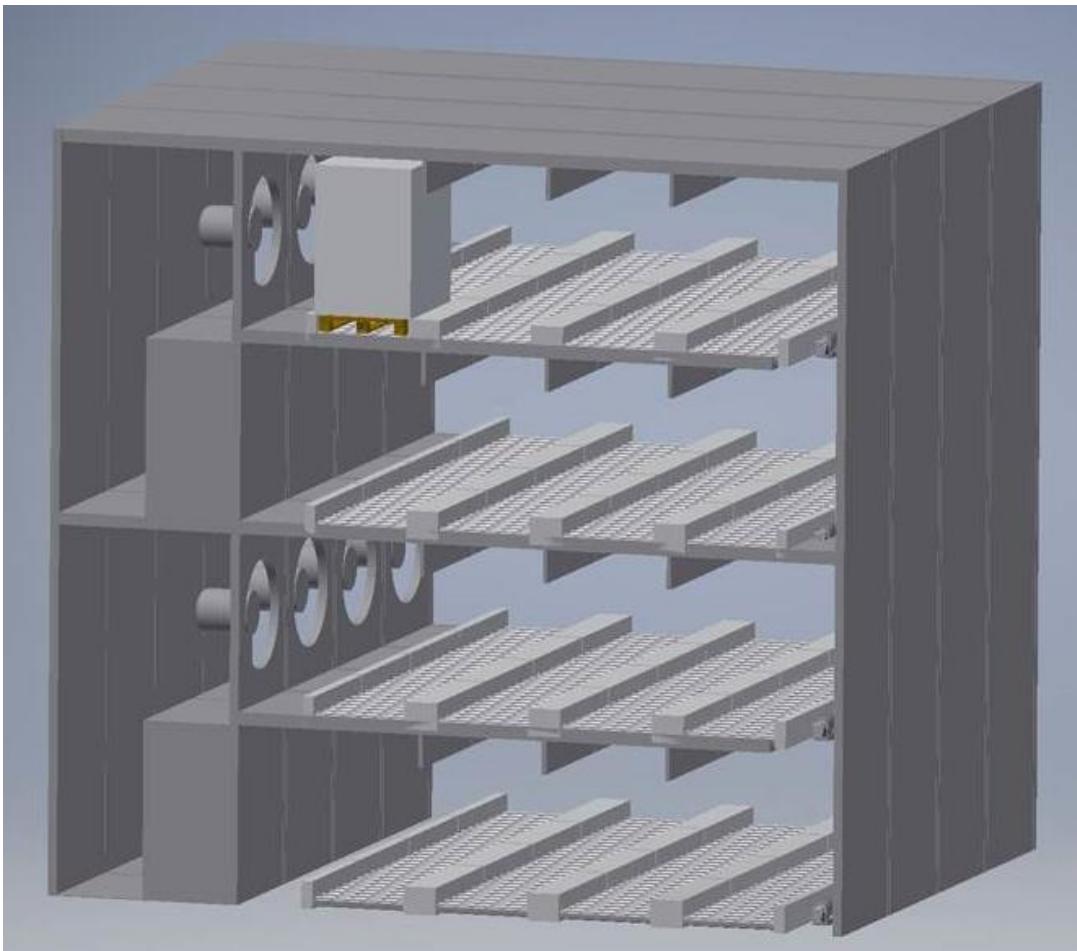
# Neptun mellemlag

- Neptun gamle og nye version



Test no.		Air flow		Freezing time			Energy usage					
		Total	[m³/s]	Total	[h]	Improvements	[%]	Fan	Ref sys	Total	Improvements	
		[h]		[h]		[%]		[kWh]	[kWh]	[kWh]	[%]	
Reference	T19-T21	6.5		28.0	0.0	0.0%		752.7	376.3	1129.0	0.0	0.0%
CS	T23	6.5		30.0	-2.0	-7%		735.4	367.7	1103.1	25.9	2.3%

# Ny indfryser fra Hørup Maskiner



Service.: 22 50 45 73 Salg.: 25 30 15 70

# Conclusions

- Air flow:
  - 86% energy savings in the test tunnel on 36 hours freezing time
  - 62% energy savings in the industrial tunnel on 33 hours freezing time
  - 79% energy savings in the test tunnel on 31 hours freezing time with new air spacers
  - Largest energy savings at first and then gradually less
  - 11-18% energy savings by reversing the air flow in the test tunnel and 1.4 - 1.9 hours (5-7%) reduced freezing time
  - 10% energy savings by reversing the air flow in the industrial tunnel and 1,6 hours (6%) reduction in freezing time

# Conclusions

- Air distribution in the tunnel:
  - 93% energy savings in the test tunnel by using baffles
  - Important to reduce the air flow and utilize the freezers cycle time to save energy
- Air spacers:
  - 4.9 hours reduction in freezing time by using new air spacers
- Claus Sørensen are implementing findings of the project
- Hørup Maskiner has developed a new carton freezing tunnel based on the project
- There are huge energy savings available with very simple measures