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# ENERGY OPTIMIZATION OF BATCH FREEZING TUNNEL FOR MEAT

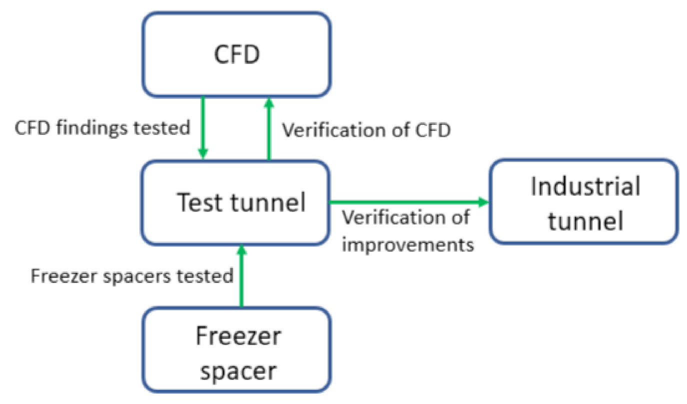
## INTRODUCTION

**Project goals**
- Optimize the running condition of a batch freezing tunnel
- 30% savings in energy consumption

**Equipment**
- Industrial batch tunnel freezer
- Laboratory test tunnel built into a container

**Looked at in the project**
- Adjusting the air flow in the freezer
- Distributing the air flow throughout the freezer
- Freezer spacers

**Done by using**
- CFD simulations
- Models
- Industrial tunnel
- Test tunnel built into a container. A scale down version of the industrial tunnel




**Optimization process**
- Find potential improvements by using models, CFD simulations
- Verification in test freezing tunnel
- Verification in industrial freezing tunnel
- Minimizing energy consumption or reducing freezing time

**Prospects for Denmark**
- 1,500,000 tons frozen in tunnel freezers per year
- The tunnel freezers use 220 GWh of electrical energy
- The estimated 30% savings lead to 66 GWh savings per year

## TEST SETUP

**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: Start from top left – fans, four tunnels, product pallets, product conveiers, Below – a look inside the tunnel, where the air stream returns, and the tunnel seen from above.*

**The test tunnel freezer**
- Scaled down version of the industrial freezer
- Used CFD to verify the down scaling
- $CO_2$ used as refrigerant
- 3 pallets and 1 row

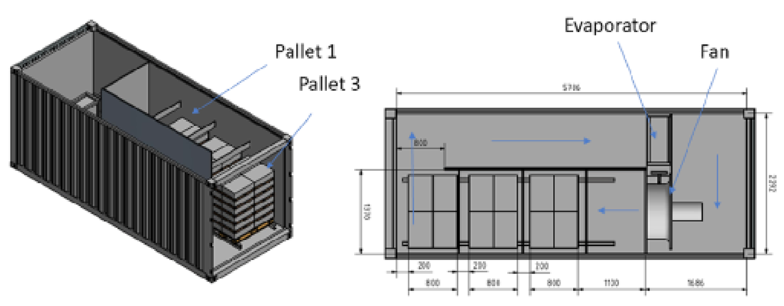



*Figure 2: Test setup built into a container. Right - the layout seen from above.*

*Figure 3: Test container in laboratory*

*Figure 4: Evaporator coil and fan*

*Figure 5: The third product pallet and return air channel*

**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

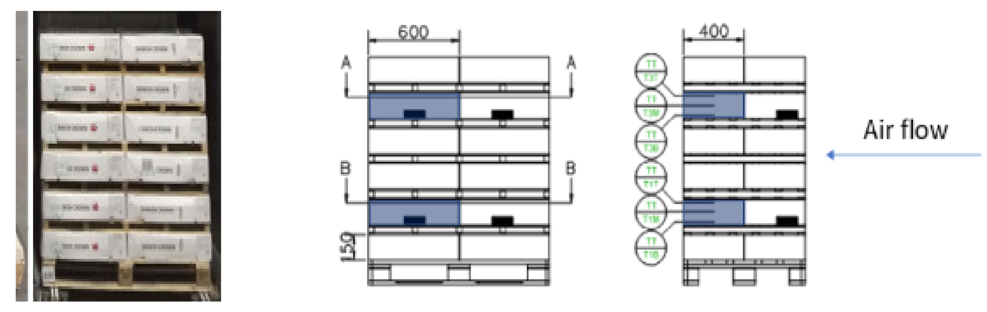



*Figure 6: Shaded boxes represent the ones with temperature sensors at three levels*

## MEASUREMENTS AND RESULTS

**Optimization**

- Minimizing the energy consumption by utilizing the logistic freezing time
- The time, which the product stays in the freezer, is mostly fixed by the loading and unloading logistics around the freezer and not the actual freezing temperature of the products

**Optimizing parameters**

**Air flow**
- Changing the air flow in the freezer to utilize the logistic freezing time of 36 hours

**Air distribution**
- Distributing the air flow through the freezer to get more air flow through the products

**Freezer spacer**
- Using another type of freezer spacers

**Method**

- Establishing a reference case
- Changing the air flow or the air distribution and compare the results to the reference case

**Energy savings for the fan contribute**

- Direct energy savings due to lower consumption
- Indirect energy savings due to additional cooling done by the refrigeration system to remove the extra fan energy
- COP of the refrigeration system is estimated to be 2.3

**Air flow**

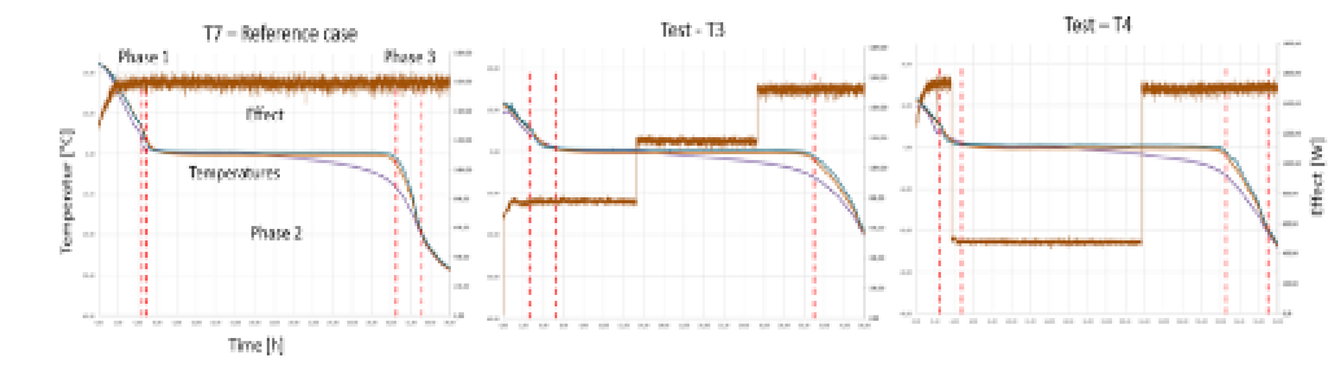



*Figure 7: Freezing temperatures in the worst box on the pallet and the effect usage on the secondary axes. The one to the left is the reference case. The other two show the tested running strategies.*

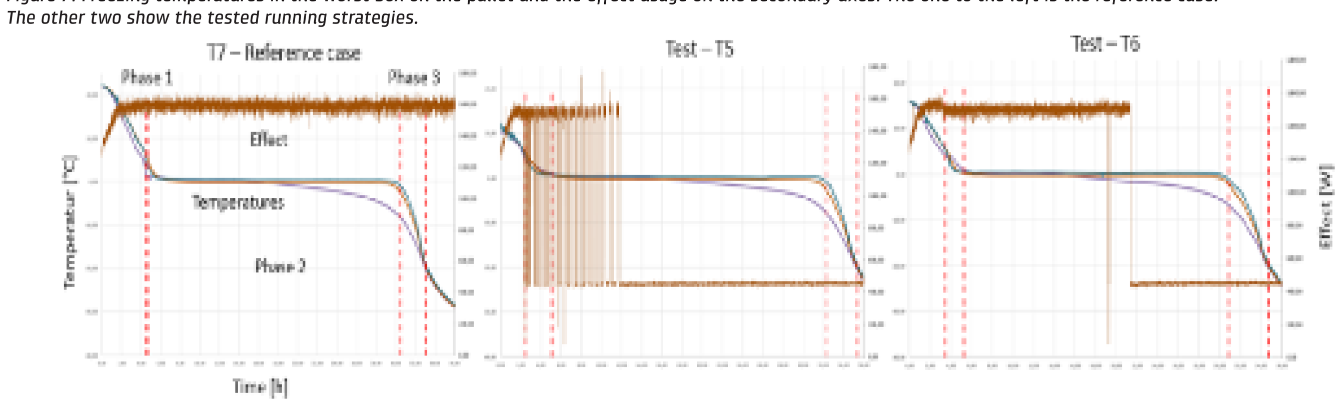



*Figure 8: Freezing temperatures (left axes) in the worst box on the pallet and the effect usage (right axes). The one to the left is the reference case. In the other two graphs, the air set point is -30°C and -32°C, respectively*

**Air distribution**

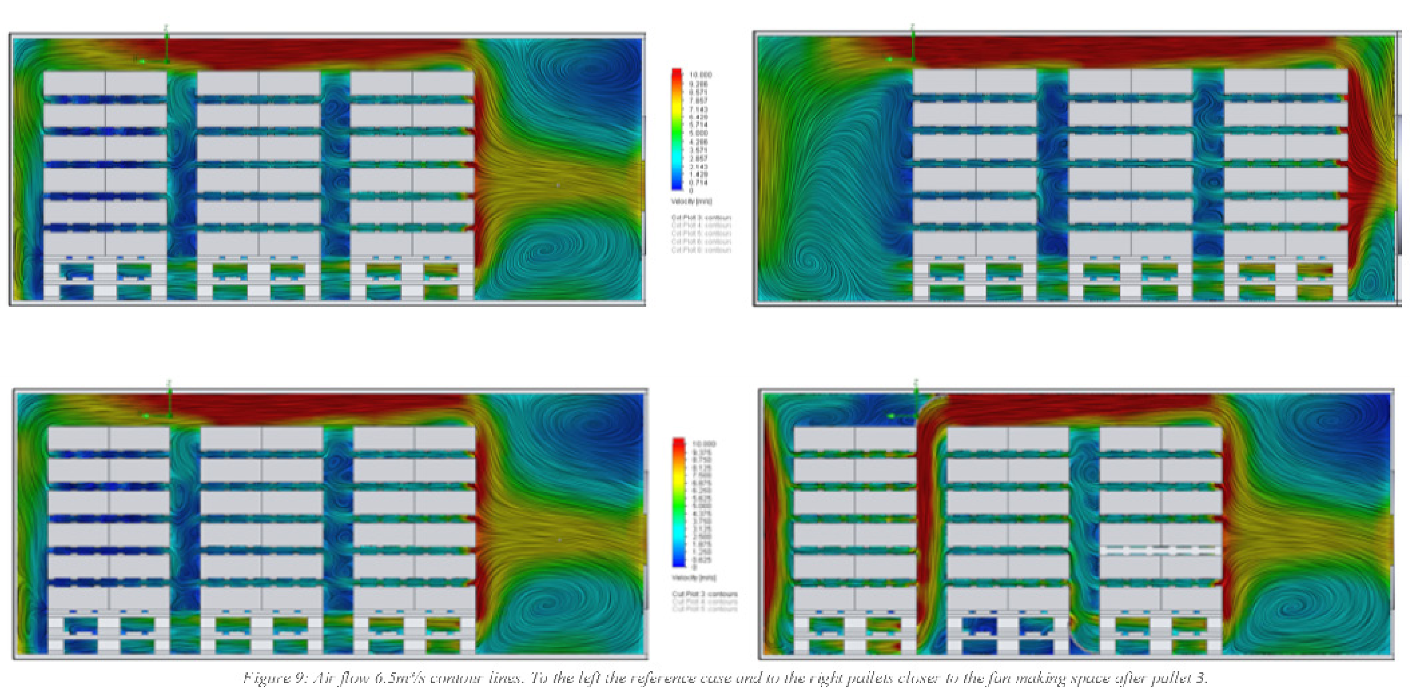


*Figure 9: Air flow 6.5m³/s contour lines. To the left, the reference case and to the right, pallets closer to the fan making space after pallet 3.*

**Test T3 and T4**
- The air flow controlled by the temperature out of the last pallet
- Increased freezing time 3.0/1.3 hours - though within the 36-hour window
- Considerable energy savings: 60% / 38.8%.

| | Test no. | Air flow | Freezing time | | | Energy usage | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total | Impovements | | 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. | 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% |

*Table 1: Freezing time and energy savings when controlling the air flow by the temperature of the air from the last pallet.*

**Test T5 and T6**
- The air flow increased in fixed steps
- Increased freezing time 3.7/4.7 hours - though within the 36-hour window
- Considerable energy savings: 24.5% / 40.7%.

| | Test no. | Air flow | Freezing time | | | Energy usage | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total | Impovements | | 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% |

*Table 2: Freezing time and energy savings when controlling the air flow.*

**Test T9**
- The first pallet in the test tunnel is moved closer to the fan
- Reduced freezing time by 3.0 hours
- Energy usage nearly the same

| | Test no. | Air flow | Freezing time | | | Energy usage | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total | Impovements | | 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% |
| Air | T9 | 6,5 | 26,8 | 3,0 | 9,9% | 57,8 | 25,1 | 82,9 | -1,6 | -1,9% |

*Table 3: Freezing time and energy savings when moving the pallets closer to the fan compared to the reference case.*

**Test T11 and T11b**
- Using baffles to direct the air flow
- Second run to try to match the freezing time of the reference case
- Reduced freezing time by 3.2 hours with same air flow as for reference case
- Reduced energy usage for the reduced air flow by 67.7%

| | Test no. | Air flow | Freezing time | | | Energy usage | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total | Impovements | | 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% |
| | T11 | 6,5 | 26,6 | 3,2 | 10,6% | 56,6 | 24,6 | 81,2 | 0,1 | 0,2% |
| | T11b | 4,1 | 30,8 | -1,0 | -3,5% | 18,3 | 8,0 | 26,3 | 55,1 | 67,7% |

*Table 4: Freezing time and energy savings when using baffles compared to the reference case.*

## CONCLUSION

**Test T7 and T8**
- The air flow fixed throughout 36 hours
- The freezing time to reach −20°C and the energy to fans shown for the tested air flow rates
- Total energy savings of 86% compared to reference case
- 80% savings are obtained at a freezing time just above 34 hours by using half the air flow compared to the reference case, i.e. 3.75m³/s

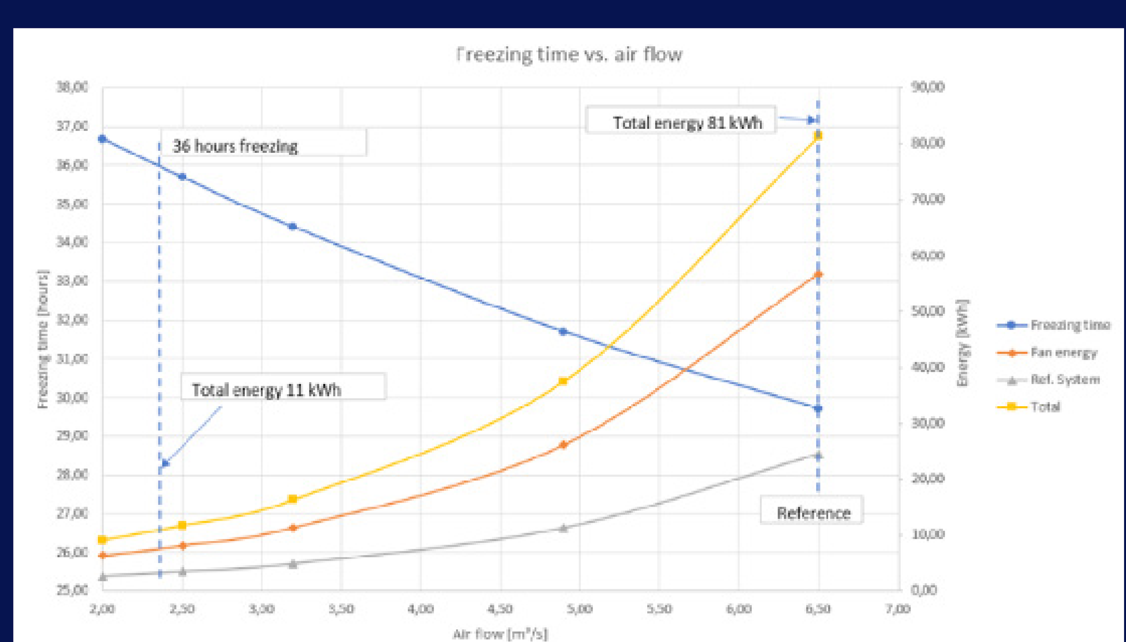



*Figure 10: Total freezing time and energy usage of fan for various air flows for wooden spacers.*

**Test T14 and T17**
- The air flow fixed throughout 36 hours
- The freezing time to reach −20°C and the energy to fans shown for the tested air flow rates
- Reduction in freezing time compared to wooden spacers is 2.2 hours
- Energy savings of 46kWh if same freezing time, i.e. 45% savings
- Unrealistic to increase the air speed to shorten the freezing time from 36 hours to 24 hours

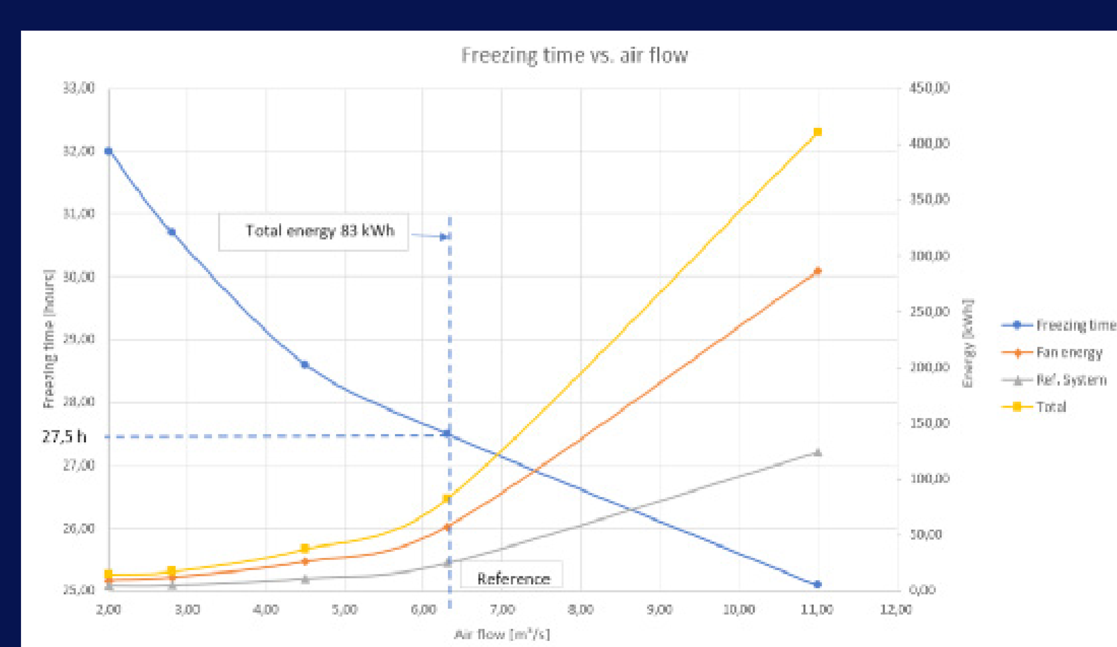



*Figure 11: Total freezing time and energy usage of fan for various air flow for NFSII spacers.*

**Air flow**
- Reducing air flow saves considerable amount of energy
- 86 percent energy savings when utilizing the 36 hours freezing time
- First part of the air flow reduction is most important
- 80 percent savings can be obtained by halving the air flow and two hours of safety on the freezing time still remain

**Freezing spacers**
- Reduces the freezing time for the same energy usage
- Energy savings of 45 percent is obtained for the same freezing time for wooden freezer spacer and NFSII

**Air distribution**
- 67.7 percent energy savings by using baffles for the same freezing time
- 93 percent energy savings can be obtained by combining baffles and reducing the air flow

**General conclusion**
- Energy savings obtained in the project are higher than the ones stated in the project goals
- Measurements are now being conducted at the site to verify the findings of the project