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Energy savings from improved air distribution in chilled food manufacturing facilities

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1. INTRODUCTION

1.1 Chilled Food Manufacturing Facilities

- Rely heavily on refrigeration in order to maintain low temperatures during processing of chilled food products.
- Facilities are normally maintained at temperatures in the range between +4 to +12 ^{o}C depending on the type of product.
- Refrigeration can account for up to 60% of the total energy consumption of the facility.
- Chilled food processing normally takes place in large spaces with high ceilings.
- Cooling is normally provided by ceiling mounted fan coil units or diffusers using the 'air mixing' principle.

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1. INTRODUCTION

1.2 Air Distribution Importance

- Create an environment capable of maintaining food quality.
- Temperature and humidity homogeneity around the food product in order to maintain its quality.
- Provide an acceptable environment for the workers in terms of thermal comfort.

1.3 Scope Of The Research

- Aims to improve the efficiency of cold air temperature distribution in chilled food processing areas.

→ Reduction of the overall energy consumption of the refrigeration plant.

→ Associated CO_2 emissions.

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1. INTRODUCTION

1.4 Research Methodology

- Understanding, modelling and replication of the air flow and the temperature distribution in existing chilled food facilities.
- Development of a tree-dimensional model based on computational fluid dynamics (CFD).
- Validation of the model.
- Building of a scaled experimental test rig and CFD model.
- Use of the model to investigate different air distribution solutions.
- Implementation of most promising solution at the laboratory.
- Industrial application of prototype.

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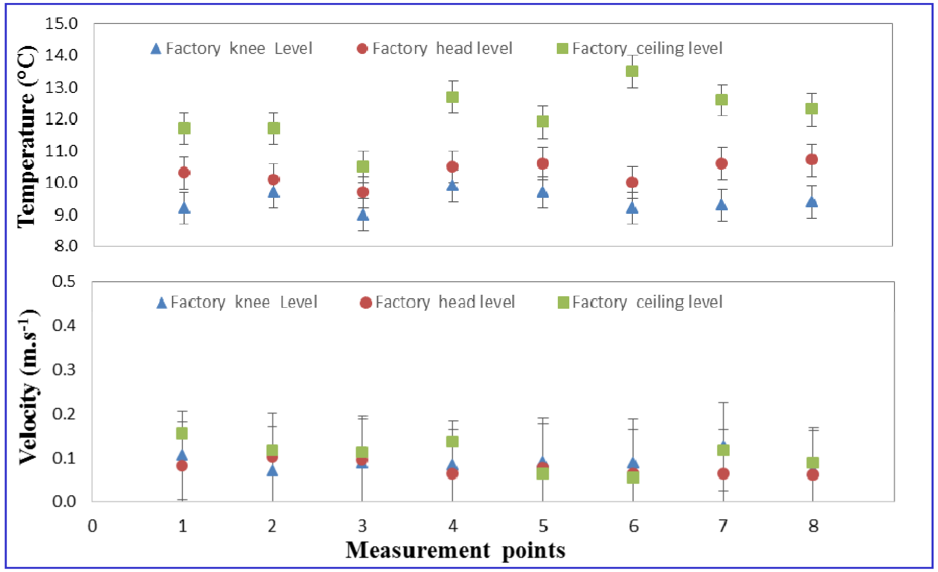
2. CASE STUDY

Chilled Food Processing Facility

Air distribution via fabric ducts

Air temperature and velocity measurements



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2. CASE STUDY

Chilled Food Processing Facility

3D Model of the Processing Facility

Numerical model description

- Steady state 3-dimensional CFD model solved using the commercial ANSYS FLUENT® package.
- Model was designed using the actual dimensions of the chilled food processing area.
- The SST-k-ω turbulence model was used to predict actual measured data.

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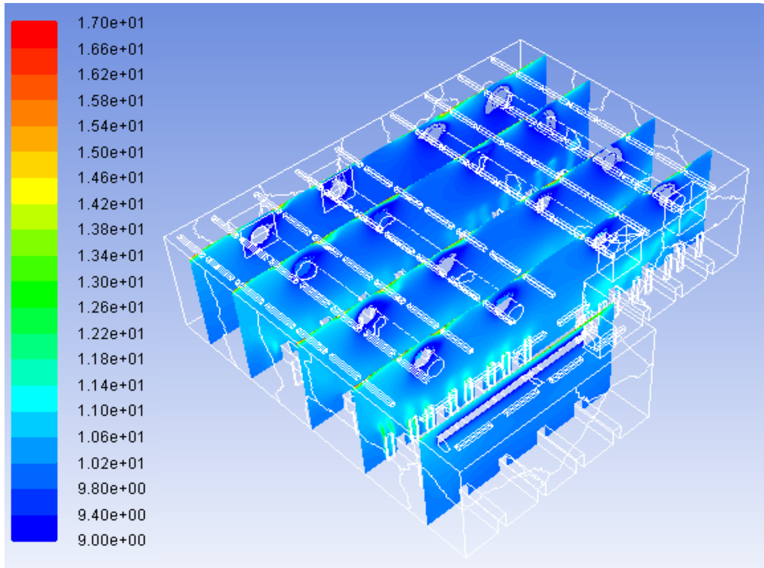
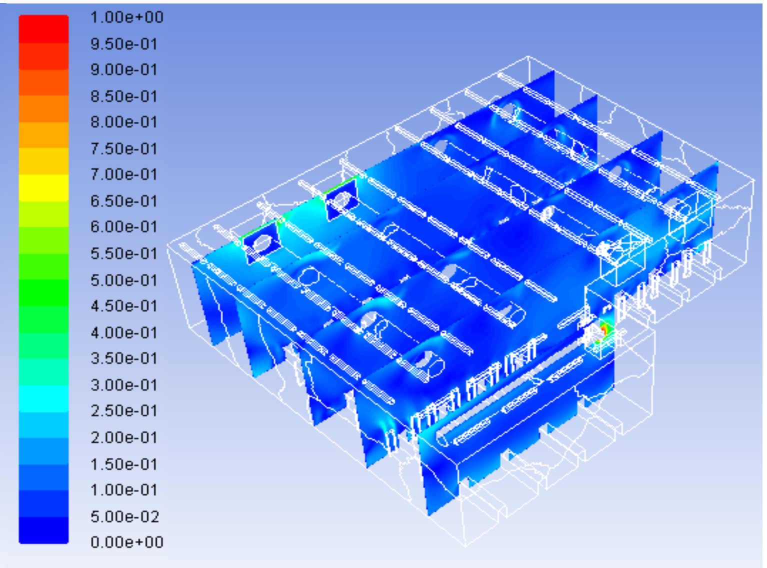
2. CASE STUDY

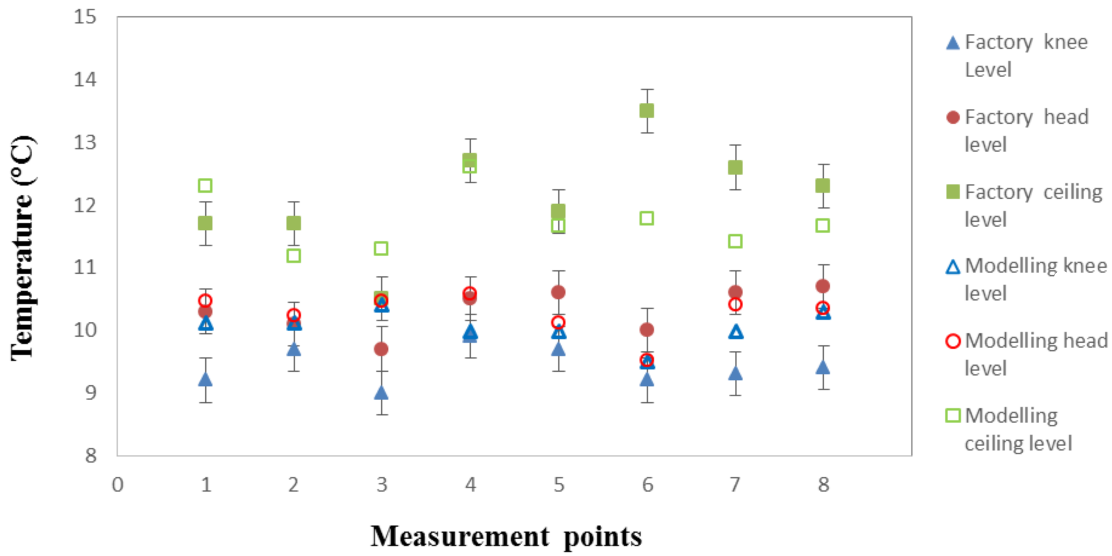


CFD modelling of air temperature in the space (ºC).



CFD modelling of air velocity in the space ($m.s^{-1}$).

3D Model validation



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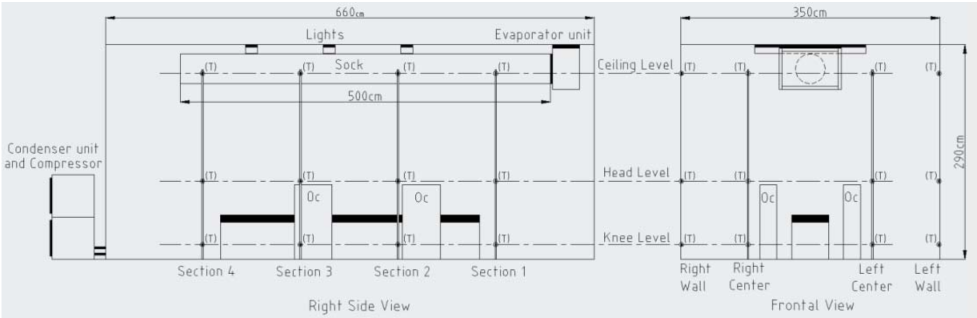
3. SCALED TEST FACILITY

3.1 Experimental Test Facility



Outline of the experimental test facility with air distribution via fabric duct at ceiling level, reference case.

Test facility, reference case.

- The chamber volume, 2.9 m (H) x 6.6 m (L) x 3.5 m (W).
- The fabric duct, 50 cm in diameter and 500 cm in length.
- Temperature sensors (T) were located at knee level, head level and ceiling level (± 0.5 ºC).
- Air velocity measured with an air flow meter TSI TA465-P (± 3 %).
- The air temperature in the test chamber set to 9.7 ºC.

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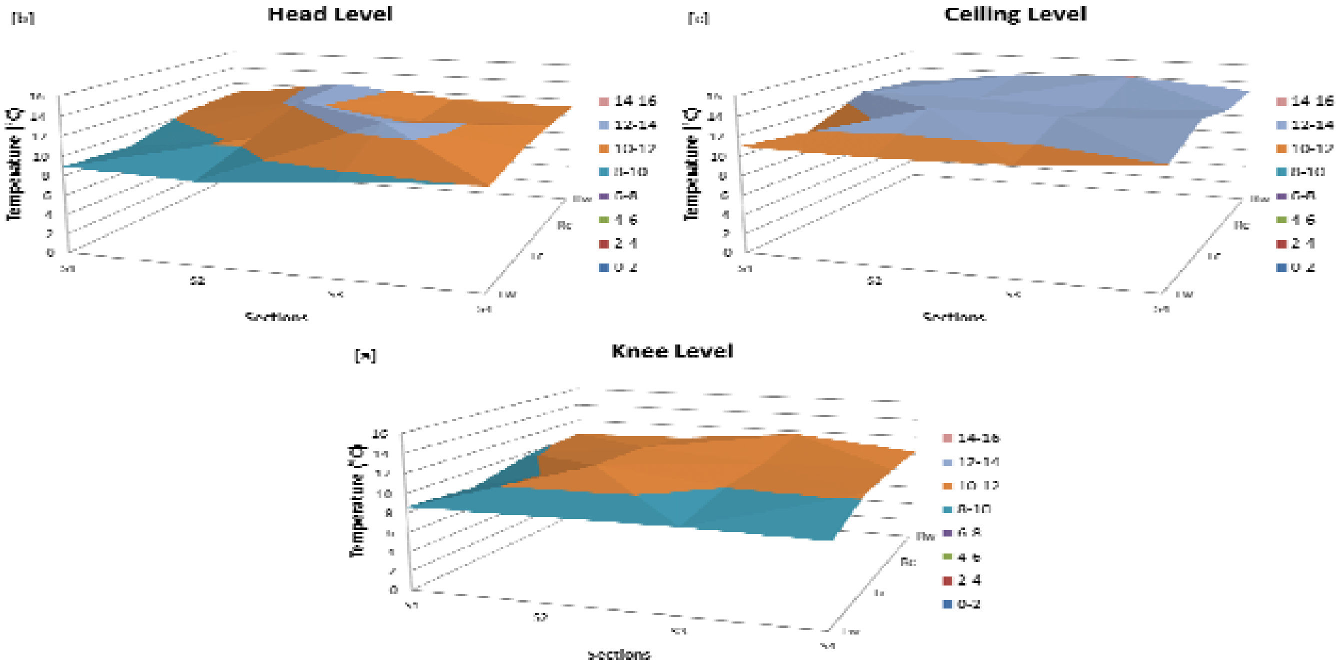
3. SCALED TEST FACILITY

3.2 Experimental Results



Temperature profiles at different heights, [a] Knee Level, [b] Head Level and [c] Ceiling Level.

- Temperatures varied from 8.1 ºC and 13.9 ºC while the average temperature values measured at knee, head and ceiling level were 9.9 ºC, 10.6 ºC and 12.4 ºC, respectively.
- The lowest temperatures were measured at knee level and highest at ceiling level.

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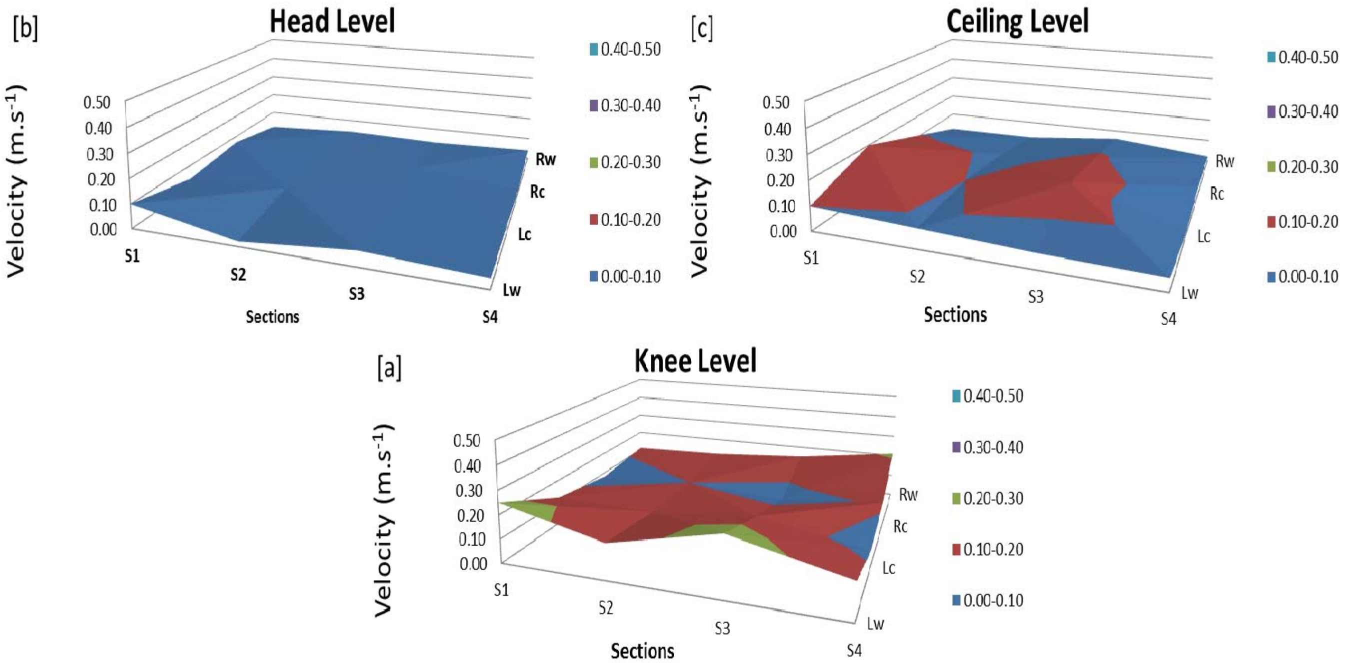
3. SCALED TEST FACILITY

3.2 Experimental Results



Velocity profiles at different heights, [a] Knee Level, [b] Head Level and [c] Ceiling Level.

- Velocities varied between 0.02 and 0.25 $m.s^{-1}$ with the highest values observed at knee level.

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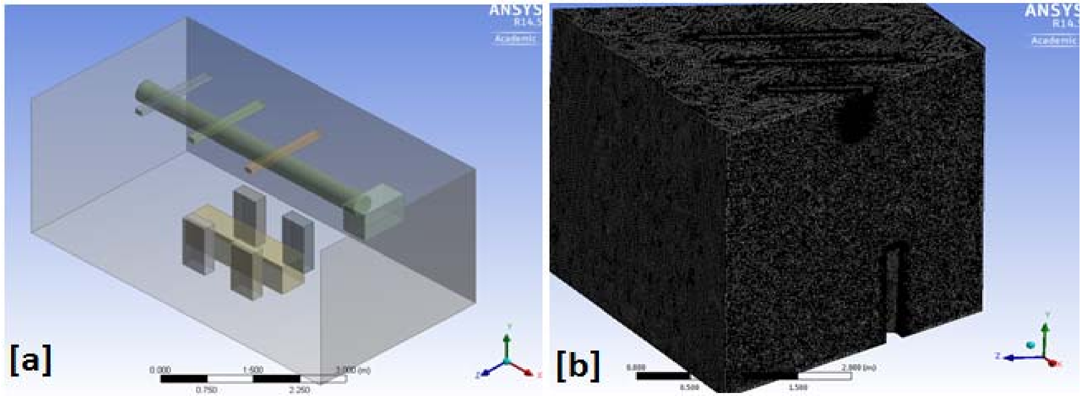
3. SCALED TEST FACILITY

3.3 CFD Model



[a] 3-D model and [b] Model mesh cross section.

Numerical model Boundary conditions

- Air supply temperature was set at 7 ºC.
- Each occupant was defined as a rectangular box with 1.57 m^2 surface area with 150 W sensible thermal load.
- Lighting heat load was set at 30 $W.m^{-2}$ floor area.
- The thermal boundary conditions of the surrounding walls were estimated considering a wall temperature of 13 ºC.

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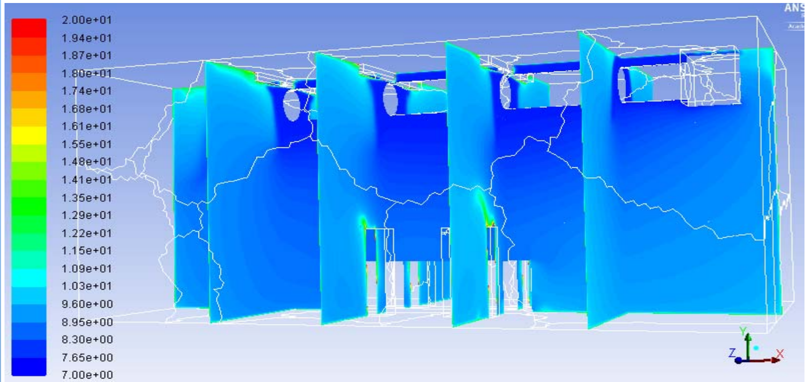
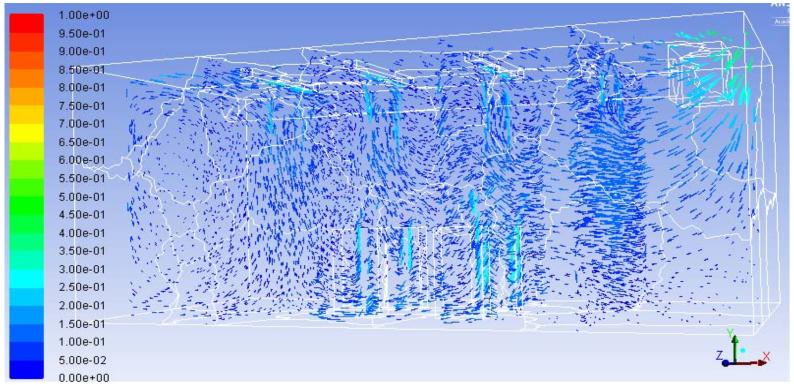
3. SCALED TEST FACILITY

3.3 CFD Model

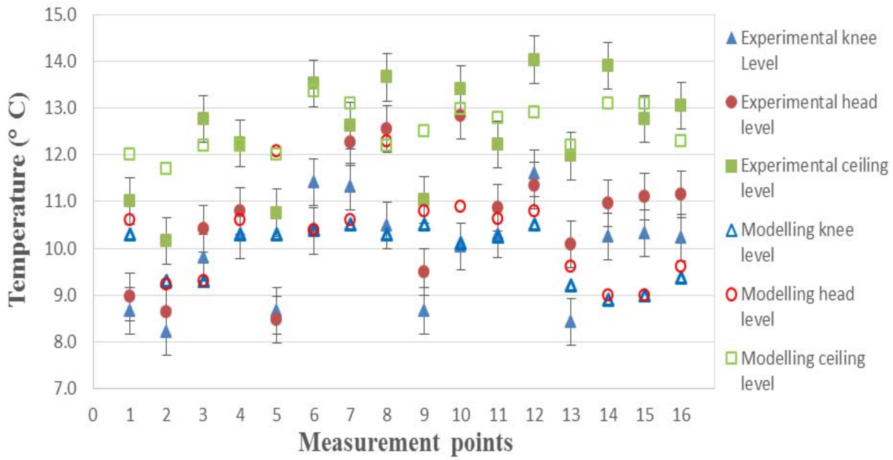


CFD modelling of air temperature in the space (ºC).



CFD modelling of air velocity in the space ($m.s^{-1}$).

- Supply temperature from the air fabric duct at 7 ºC
- Air velocities were very low and varied between 0.01 and 0.3 $m.s^{-1}$
- The temperature in the bulk of the space varied between of 8.9 ºC and 13.0 ºC



3D Model validation

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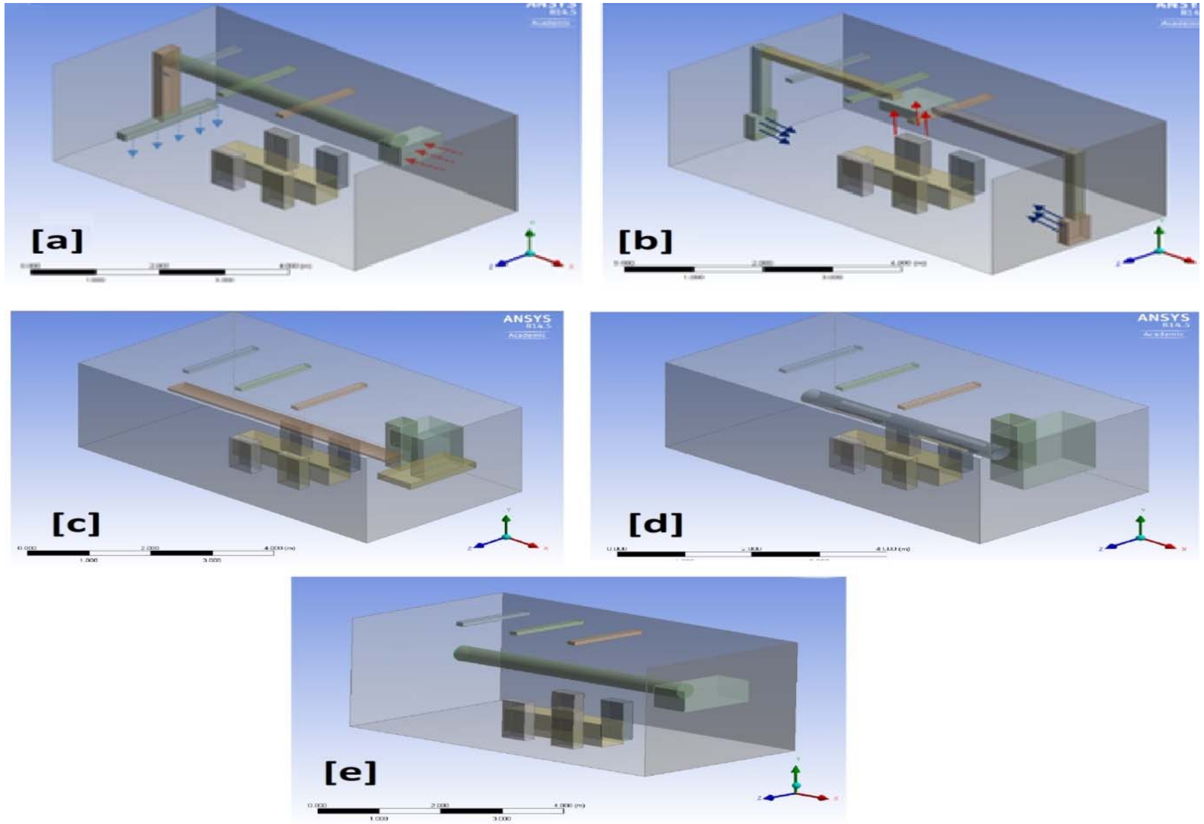
3. SCALED TEST FACILITY

3.3 CFD Model



3-D models [a] air distribution via displacement ventilation with one diffuser, [b] air distribution using displacement ventilation system with two 1-way supply diffusers, [c] air distribution system with a half fabric duct at a medium level, [d] air distribution system via slot diffusers and [e] air distribution via fabric duct at medium level.

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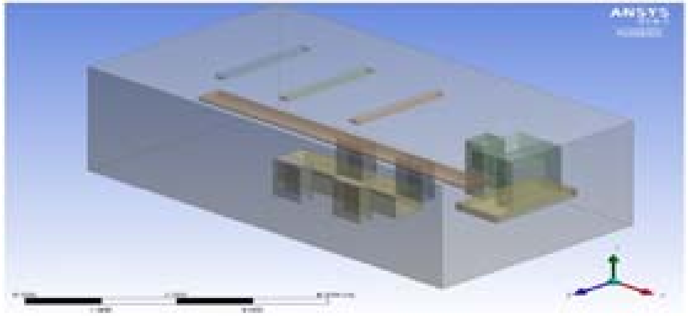
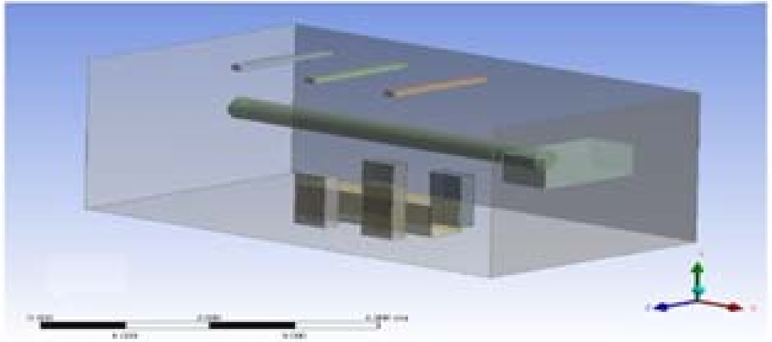
3. SCALED TEST FACILITY

3.3 CFD Model





Air distribution system with a half-fabric duct at a medium level

Air distribution via whole fabric duct at medium level.

For both, air temperature varied between 7 ºC and 14.0 ºC. The temperature at the production line level up was to 7-7.5 ºC. Homogeneous flow pattern along the occupied area with increased temperature stratification.

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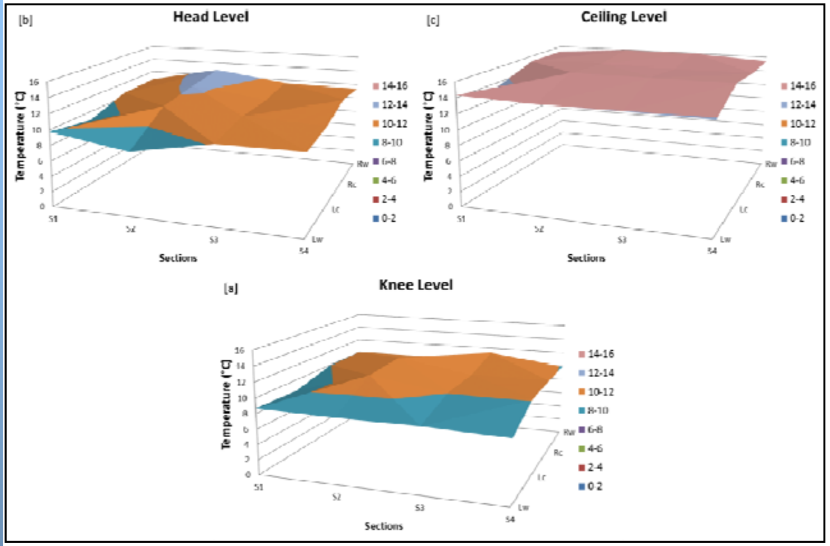
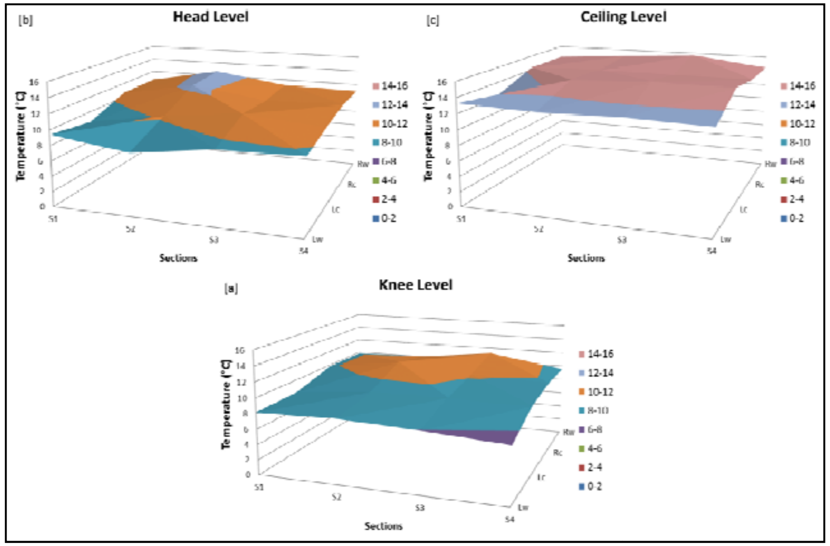
3. SCALED TEST FACILITY

3.4 Improved air temperature distribution

Temperature profiles at different heights



Fabric duct



Half-Fabric duct

- **Reference**: Temperature (from 8.1 ºC and 13.9 ºC), average temperature values measured at knee, head and ceiling level were 9.9 ºC, 10.6 ºC and 12.4 ºC, respectively.
- **Half-fabric duct at medium level:** Temperature (from 7.5 ºC and 15.1 ºC), average temperature values at knee, head and ceiling level were 9.3 ºC, 10.5 ºC and 14.3 ºC, respectively.
- **Fabric duct at medium level:** Temperature (from 6.5 ºC and 16.0 ºC), average temperature values at knee, head and ceiling level were 9.8 ºC, 10.7 ºC and 15.2 ºC, respectively.

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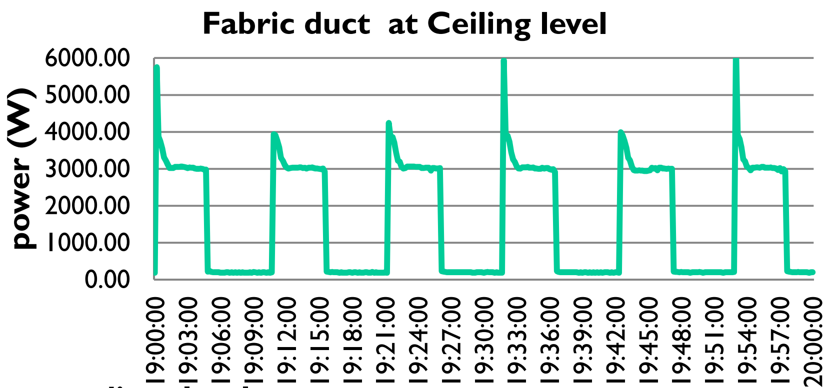
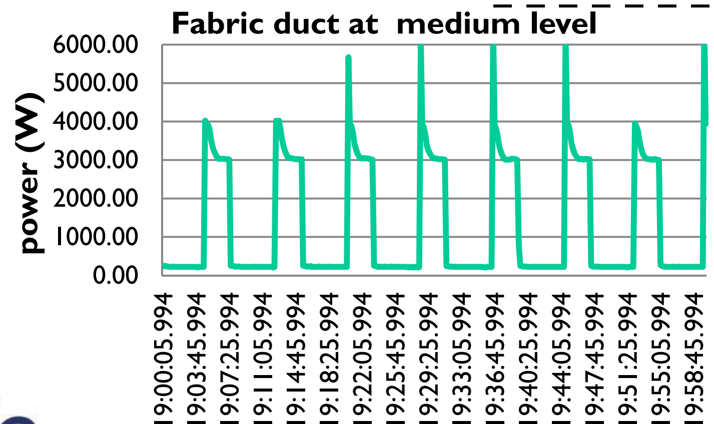
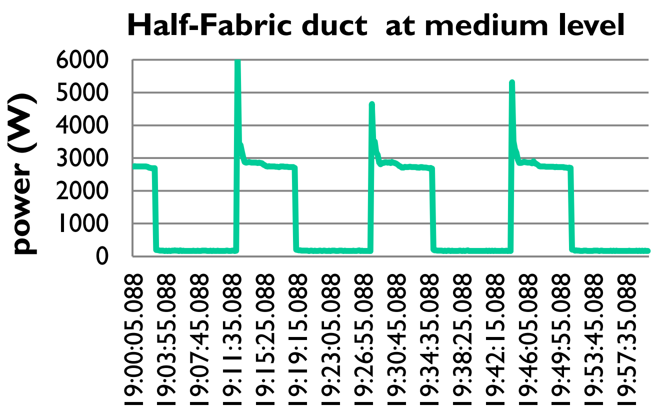
3. SCALED TEST FACILITY

3.5 Energy consumption

17 hour experimental period power consumptions			
	Fabric duct at Ceiling level	Fabric duct at medium level	Half-Fabric duct at medium level
Total consumption (kWh)	25.28	22.88055556	23.50822222
Hourly average (kWh)	1.49	1.345915033	1.383062592
Energy saving (%)	Reference case	9%	7%







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4. CONCLUSIONS

- Current configurations of air distribution systems in food processing factories tend to cool the whole processing room.
- Fabric ducts provide air flow more uniformly and at lower velocities than conventional fan coil air distribution systems.
- Low velocity air distribution at low level provides more localized cooling - lower temperature at low level in the manufacturing area and higher temperatures at higher level.
- Localized cooling and temperature stratification reduces space to be cooled to low temperature and leads to lower refrigeration system energy consumption.

Next step…

- Metal based prototype is being installed and will be monitored in a food processing facility.

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Thank you for your attention

Questions ?

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