Verifying the reliability of CFD domain decomposition technique on modelling the flow field inside naturally ventilated cattle barn

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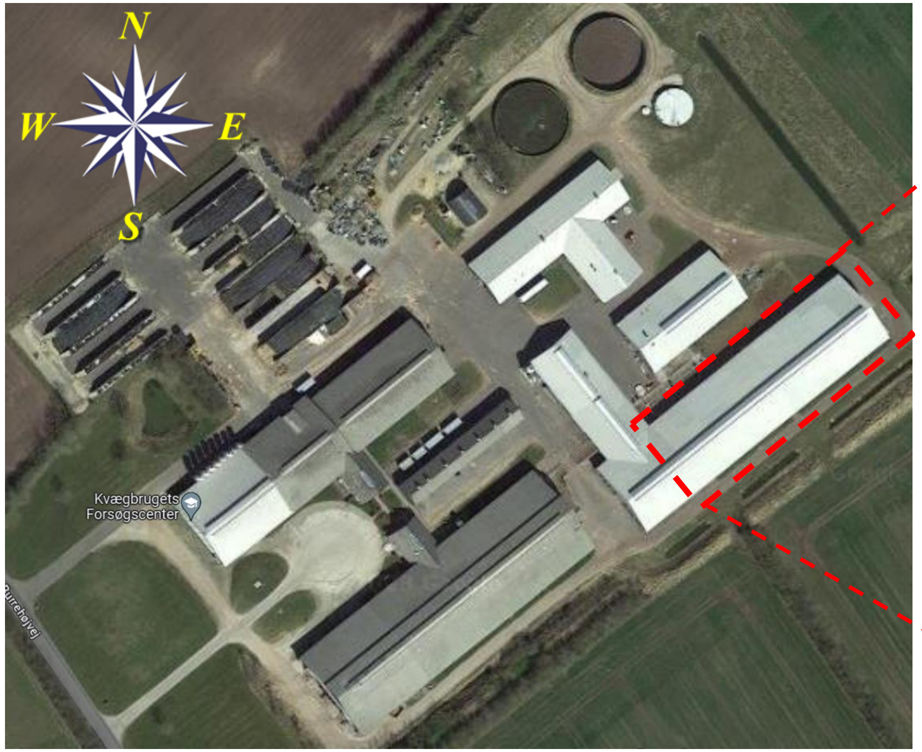
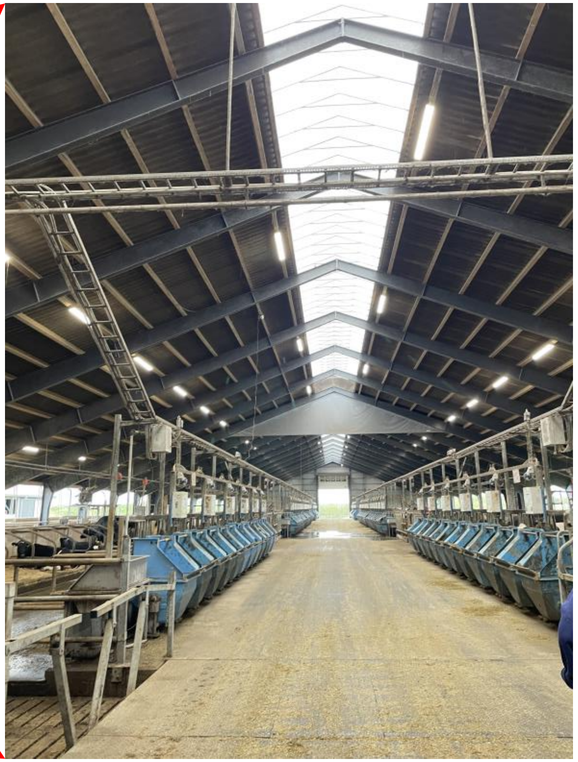
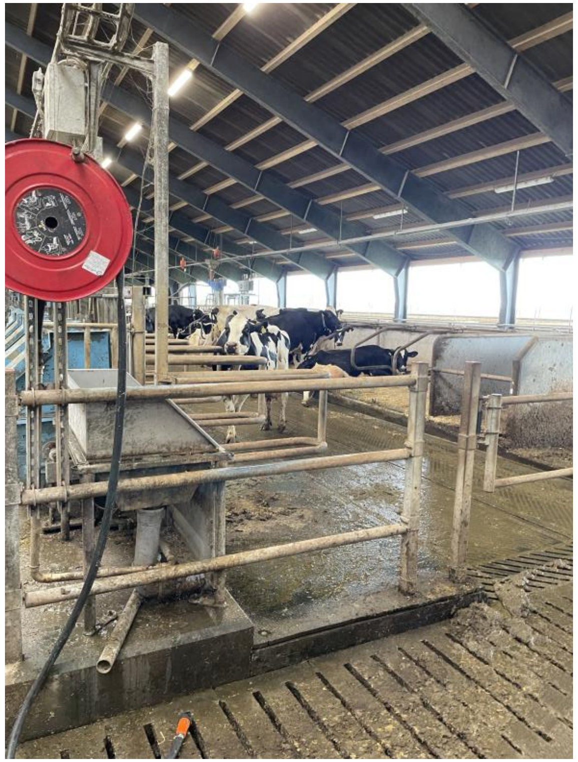
BACKGROUND

Exterior



Interior

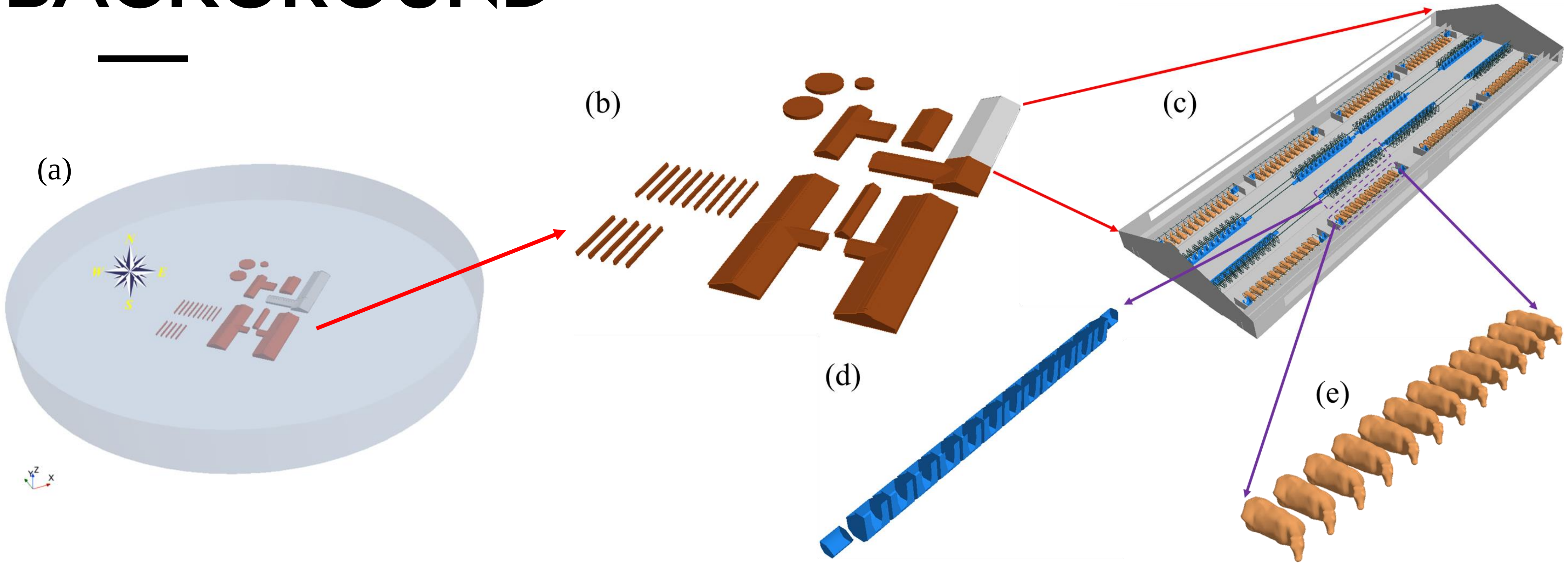




Danish Cattle Research Centre

(AU Viborg, Denmark)

BACKGROUND



(a) Large computational domain, geometric of (b) buildings in DKC, (c) target barn with roof being hidden and sidewall openings being fully opened, (d) one column of feeding tanks and (e) one column of reclining cattle in CFD modelling.

BACKGROUND

- CFD facilitate the understanding of airflow patterns in and around livestock buildings.
- Influencing factors: *exterior wind condition*, *surrounding buildings and topography*, *opening configuration*, *layouts of interior facilities*, *distribution of animals…*
- The required computational power is **extremely high and even unfordable**, especially running unsteady-state simulation!

OBJECTIVE

- Domain decomposition technique (**DDT**) divide the one-step CFD simulation into two-step simulations.
- Verify the reliability of DDT on modelling the airflow field inside naturally ventilated cattle barn

METHODOLOGY

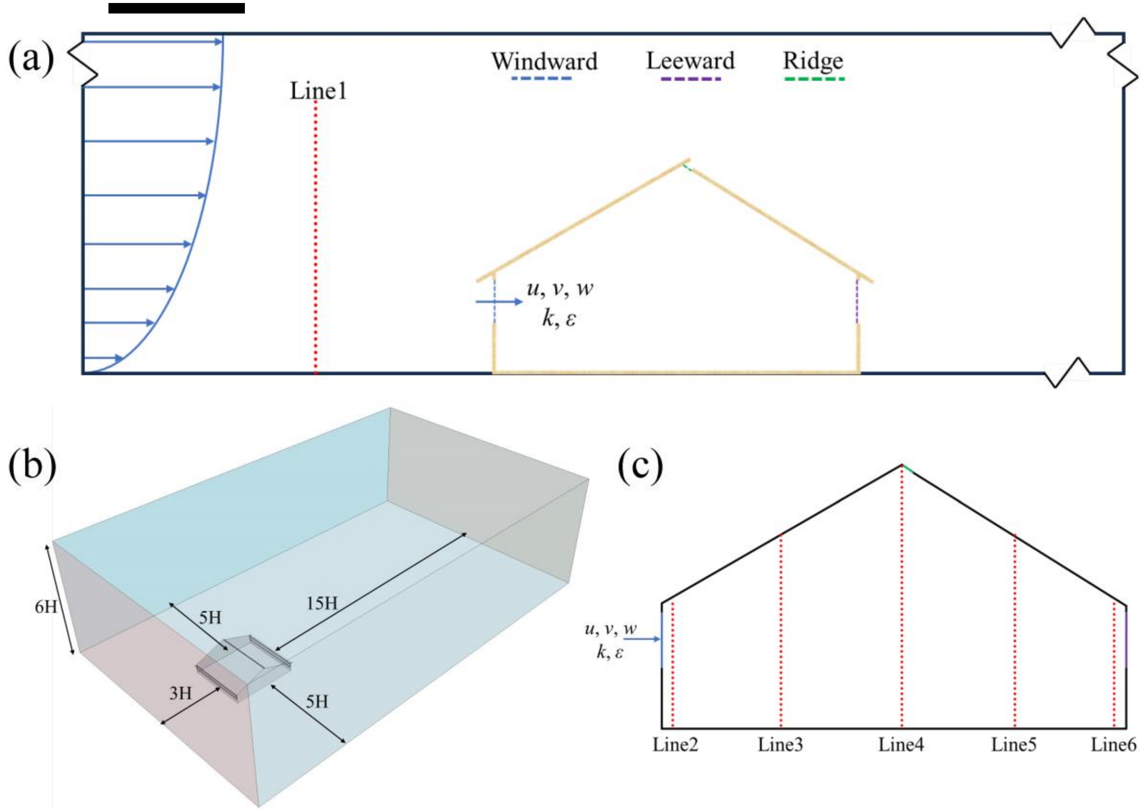


Fig. 1 – (a) Vertical section view and (b) 3D view of the whole domain in Step 1; (c) Vertical section view of the interior domain retrieved from the 'sealed' barn.

Domain decomposition technique

***Step* 1: *Exterior simulation* (*see* (*a*))**

- Inflow conditions:
  - $U(Z)=6.55\cdot(Z/0.29)^{0.161}$
  - $TI(Z)=0.156\cdot(1+Z)^{-1.469}$
- Simulation targets:
  - u, v, w, k, ε on windward opening

***Step* 2: *Interior simulation* (*see* (*b*))**

- Inflow conditions:
  - u, v, w, k, ε on windward opening from ***Step*** 1
- Simulation targets:
  - Profiles of u and w on Lines 2-6 inside the barn

Fig. 2 – Flowchart of DDT.

METHODOLOGY

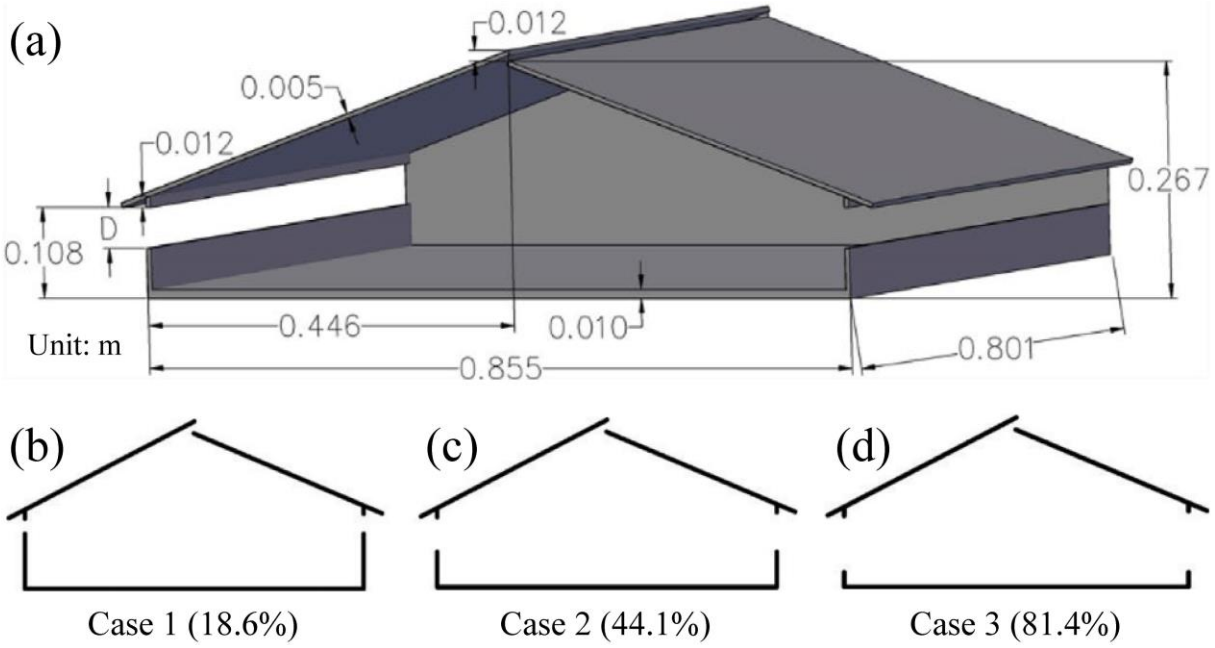
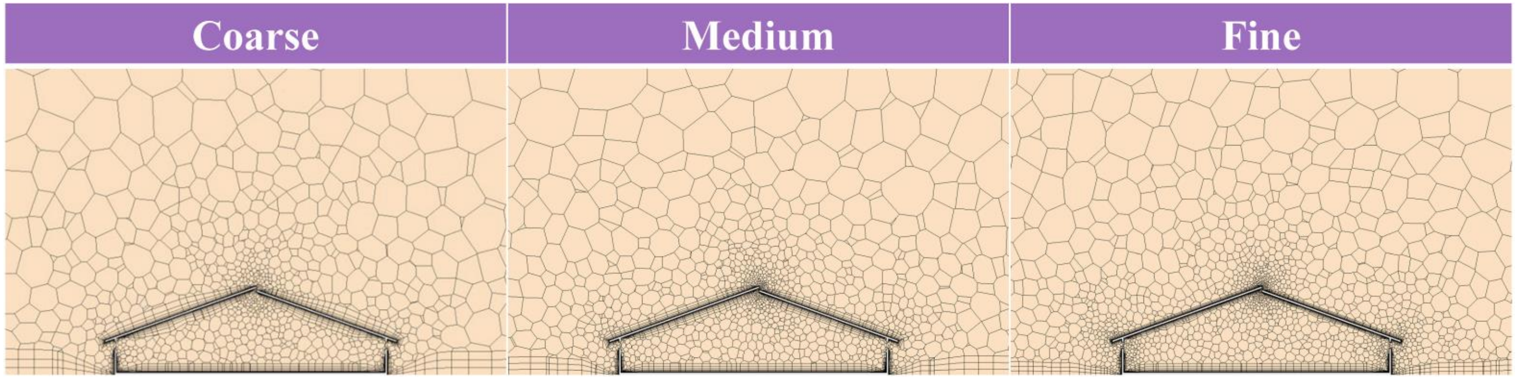


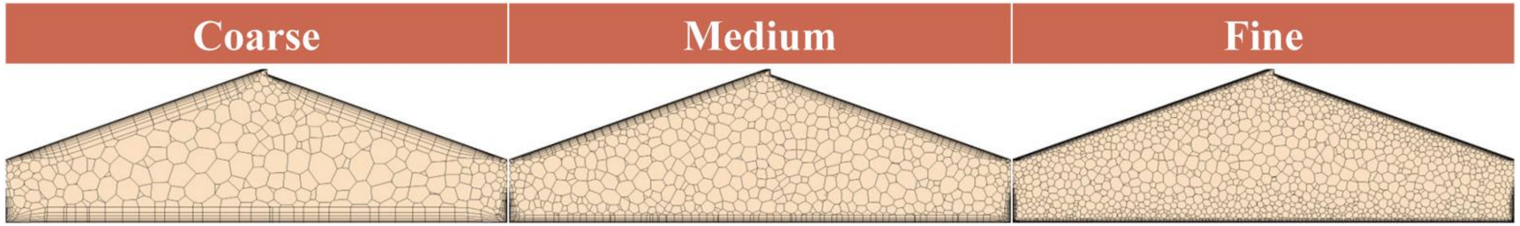
Fig. 3 – (a) sketch of scaled cattle barn with front gable wall being hidden, adopted from study by Yi, König, et al. (2018); vertical section views of cases with opening ratio of (b) 18.6%, (c) 44.1% and (d) 81.4%, adopted from study by Yi, Zhang, et al. (2018).

METHODOLOGY



160,835 cells 337,397 cells 900,979 cells

Fig. 4 – Mesh distribution at central vertical plane under three different mesh resolutions for Case 1 in Step 1.



57,393 cells 153,327 cells 626,495 cells

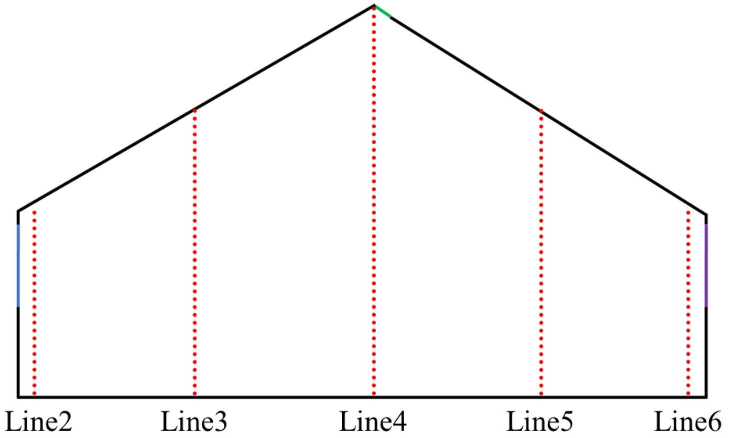
Fig. 5 – Mesh distribution at central vertical plane under three different mesh resolutions for Case 1 in Step 2.

METHODOLOGY

- Standard k - ε Two-Layer model
- Segregated flow model
- Second-order upwind scheme

RESULTS

Opening ratio: 18.6% (Small)



RMSE: 0.66

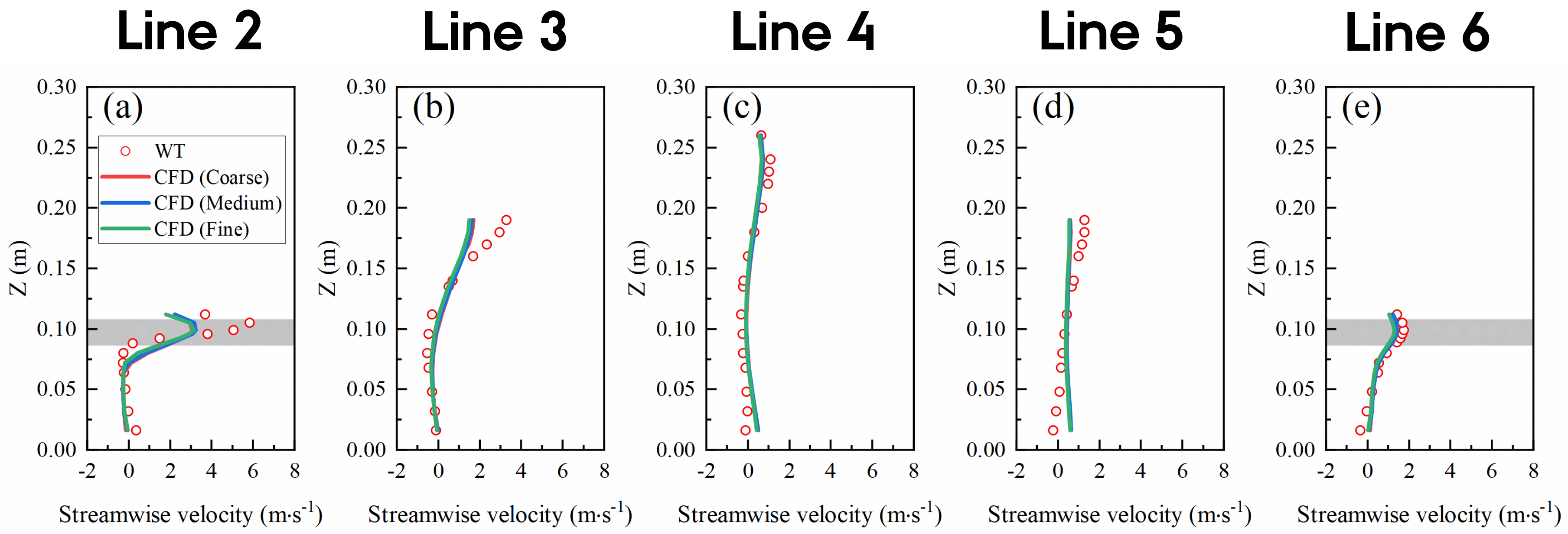
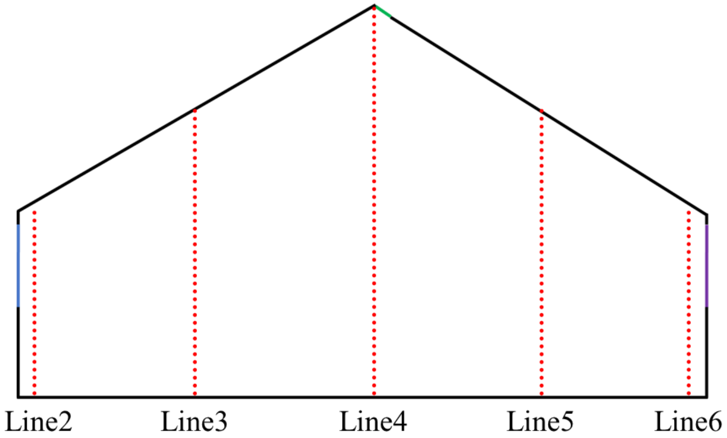


Fig. 6 – Comparisons of streamwise velocity distribution between wind tunnel (WT) measurement data and results obtained from CFD simulations under three different mesh resolutions for small openings 1 in Step 2. The shade areas in panels (a) and (e) corresponded to the sideward openings.

RESULTS

Opening ratio: 44.1% (Medium)



RMSE: 0.74

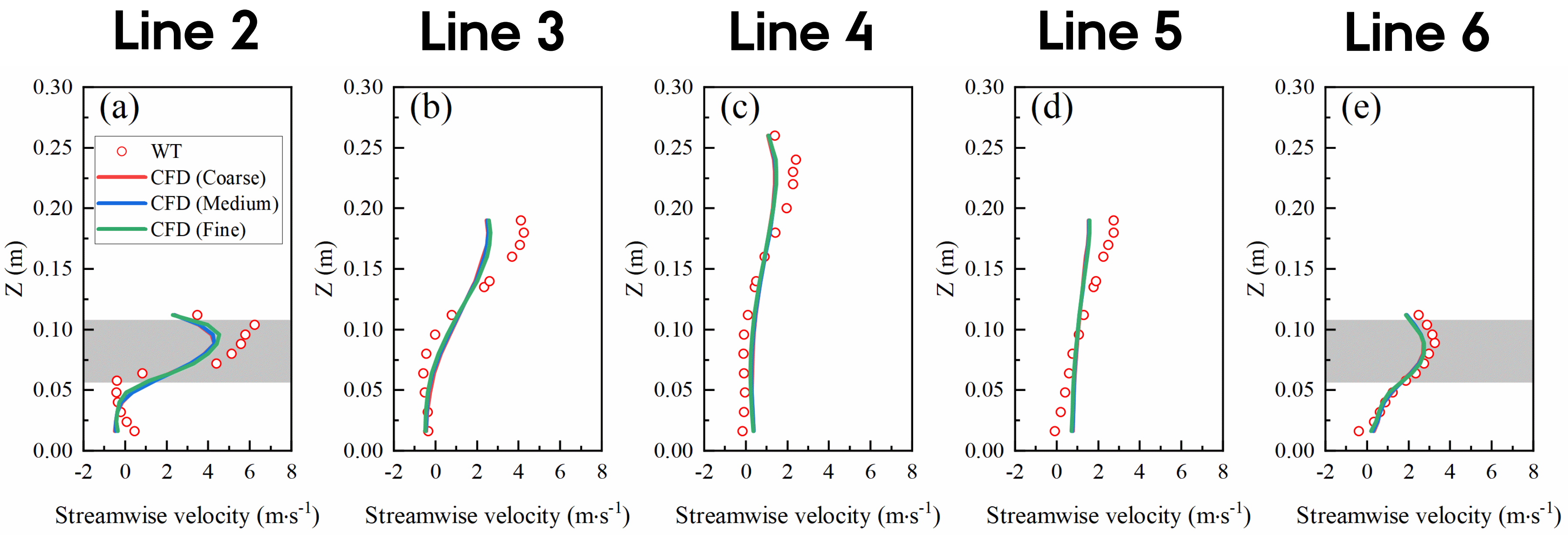


Fig. 7 – Comparisons of streamwise velocity distribution between wind tunnel (WT) measurement data and results obtained from CFD simulations under three different mesh resolutions for medium openings 1 in Step 2. The shade areas in panels (a) and (e) corresponded to the sideward openings.

RESULTS

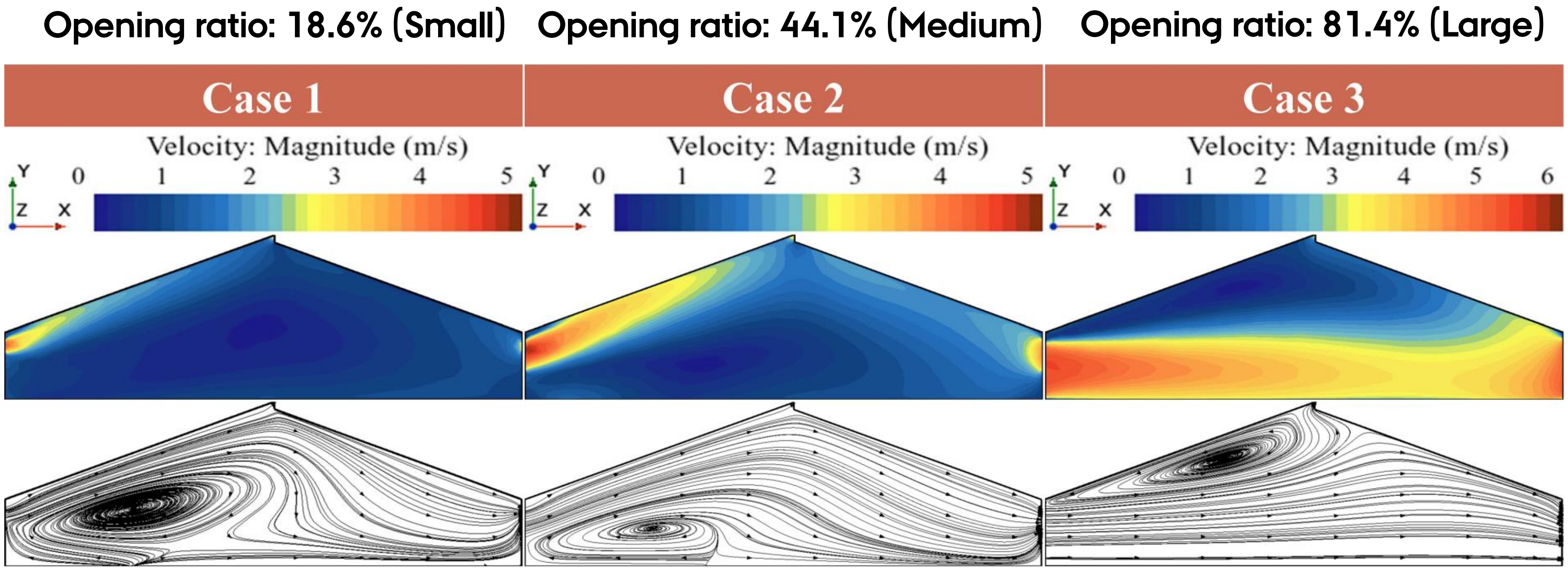


Fig. 9 – Distributions of velocity and streamlines at central vertical plane under medium mesh resolution for the three investigated cases in Step 2.

SUMMARY

- The reliability of DDT on modelling the airflow field inside naturally ventilated cattle barn were verified under isothermal condition.

- Further verifications should be conducted with the present of exterior buildings, interior facilities/animals and heat sources....

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