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Publication date:
2022

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Gao, M., Fan, J., & Furbo, S. (2022). *Numerical Investigation of a Large-scale Water Pits Heat Storage*. Poster session presented at 2022 International Conference on Solar Energy for Buildings and Industry, Kassel, Hesse, Germany.

Numerical Investigation of a Large-scale Water Pits Heat Storage

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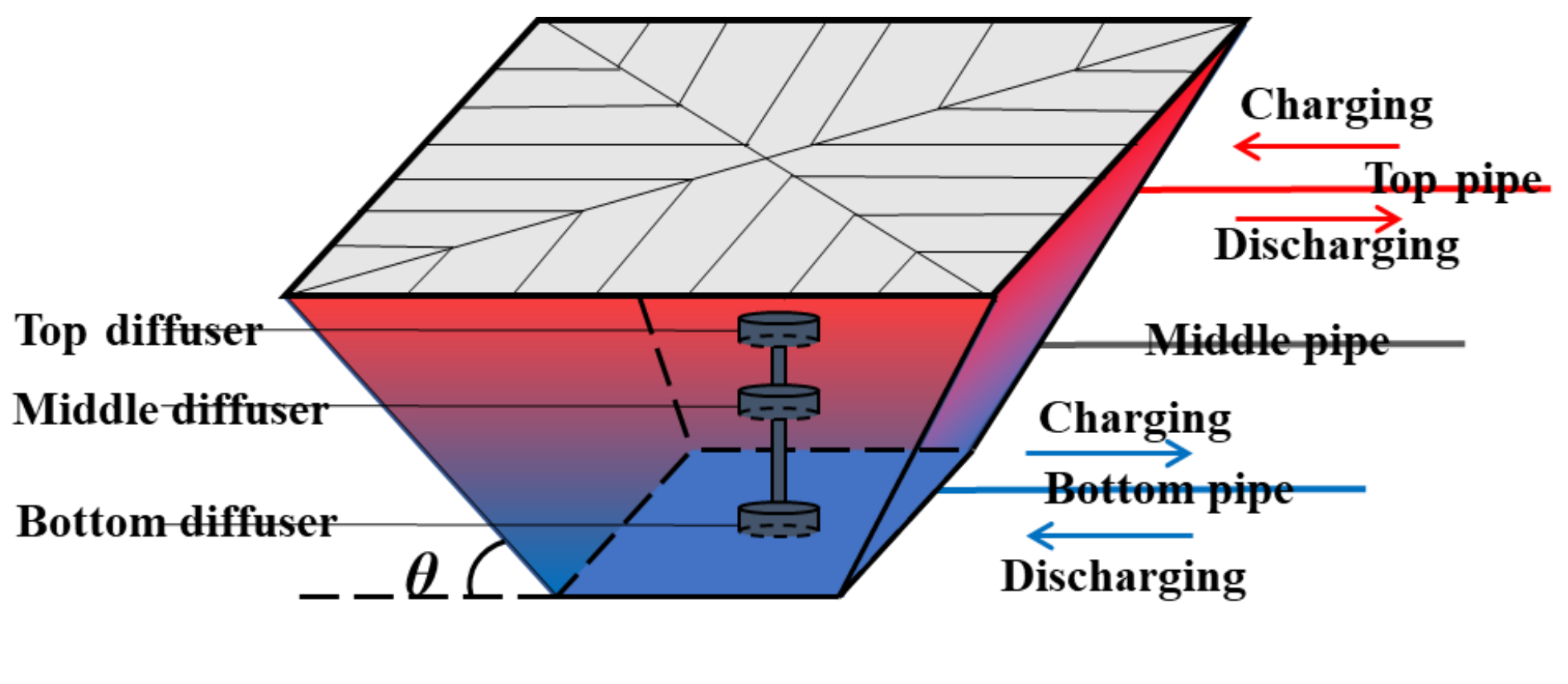
Introduction

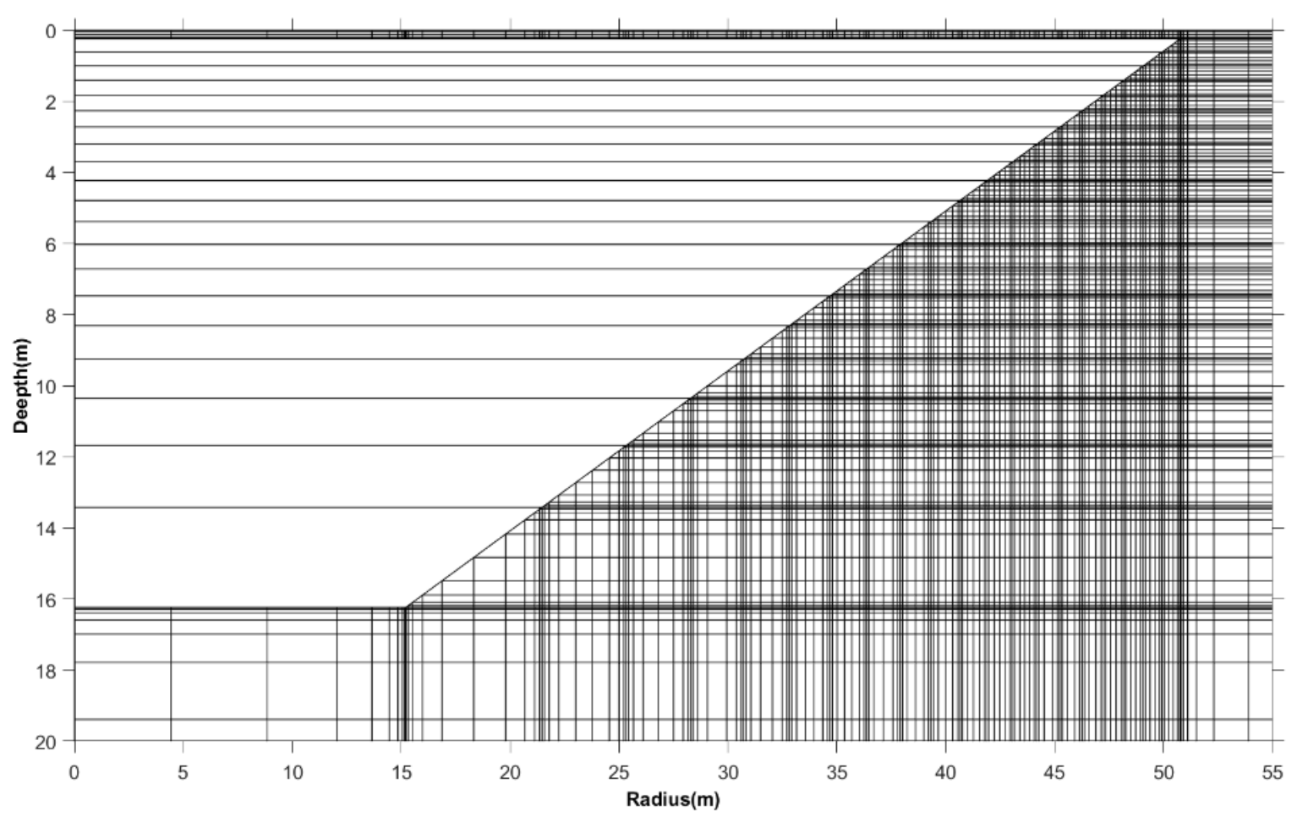
A model of PTES from TRNSYS containing 1D water pit and 2D soil is used as a research object. The measured data of 60,000 m^3 of PTES in Dronninglund, Denmark, in 2017 are utilized as input parameters and validation data. The stratification coefficient and Mix number are taken as an indicator to evaluate the stratification effect during the energy charging and discharging period. The coupling effects of layer number and time step on the computational accuracy are investigated.

Structure and grid

The geometry of the PTES at the Dronninglund SDH plant is an inverted truncated pyramid with a slope angle of 26.6°. Three diffusers are installed at the top, middle and bottom of the water pit and are switched as inlet or outlet depending on the operating strategy of the system. Hot water is delivered from the top during the night time, when the PTES is discharging energy. On sunny days hot water is fed from the top, when the PTES is charging. The meshing is shown as follows.



Inverted truncated pyramid



Mathematical description

$$V_j C_p \rho_w \frac{\partial T_j}{\partial \tau} = \left[\frac{\lambda_w (r_j - r_{j+1})^2}{(z_{j+1} - z_j)} + m_j C_p + m_{mix,j} C_p\right](T_{j+1} - T_j) + \left(\frac{1}{h_w} + \frac{\delta_{\mathrm{HDPE}}}{\lambda_{\mathrm{HDPE}}} + \frac{\delta_{\mathrm{geo}}}{\lambda_{\mathrm{geo}}}\right)^{-1} A_{side,j}(T_{side,j} - T_j) + V_{in}\rho_w C_p (T_{in} - T_j) + Q_j$$

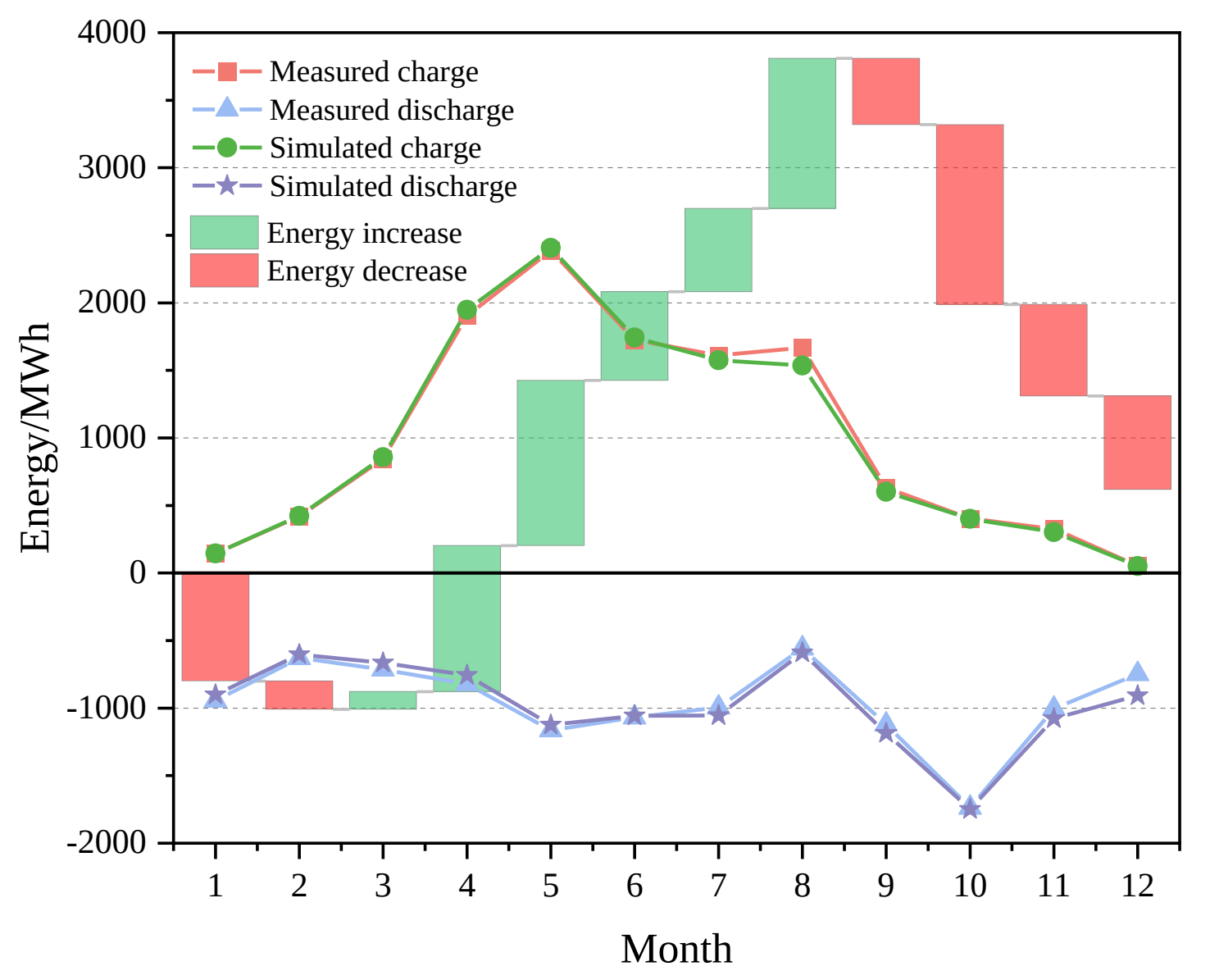
$$V_{i,k} c\rho \frac{\partial T_{i,k}}{\partial \tau} = \frac{2 \cdot \lambda_s \cdot A_{i,k+1}}{z_{k+1} - z_k}(T_{i,k+1} - T_{i,k}) + \frac{2 \cdot \lambda_s \cdot A_{i,k-1}}{z_k - z_{k-1}}(T_{i,k-1} - T_{i,k}) + \frac{(z_{k+1} - z_k)\cdot \lambda_s}{2\ln\left(\frac{r_{i+1}}{r_i}\right)}(T_{i+1,k} - T_{i,k}) + \frac{(z_k - z_{k-1})\cdot \lambda_s}{2\ln\left(\frac{r_i}{r_{i-1}}\right)}(T_{i-1,k} - T_{i,k}) + Q_{i,k}$$

$$M_c = \sum_{j=1}^{N} H_j \rho_w V_j C_p \cdot T_j \qquad M_{\mathrm{mix}} = \sum_{j=1}^{N} H_j \rho_w V_j C_p \cdot \frac{Q_{\mathrm{sto}}}{\rho_w \cdot C_p \cdot V_t} \qquad M_{\mathrm{str}} = \sum_{j=1}^{N_{thermo}} \rho_w C_p V_j H_j \cdot T_{\mathrm{hot}} + \sum_{j=N_{thermo}}^{N} \rho_w C_p V_j H_j \cdot T_{\mathrm{cold}}$$

$$\mathrm{MIX} = \frac{(M_{\mathrm{str}} - M_{\mathrm{c}})}{(M_{\mathrm{str}} - M_{\mathrm{mix}})} \qquad ST = \frac{\sum_j^N m_j (T_j - \bar{T})^2}{m_t} \qquad RMSD = \sqrt{\frac{1}{N}\sum\nolimits_{i=1}^{N}(P_{sim,i} - P_{mea,i})^2} \qquad R^2 = 1 - \frac{\sum_i (y_i - f_i)^2}{\sum_i (y_i - \bar{y})^2}$$

Validations

Item	Measured	Simulated	Deviation
Maximum temperature	84.4 °C	85.1 °C	0.7 °C
Minimum temperature	8.7 °C	8.6 °C	0.1 °C
Charged energy	12122 MWh	11994 MWh	1.1 %
Discharged energy	11504 MWh	11671 MWh	1.5 %
Internal energy change	-608MWh	-614 MWh	1.1 %
Thermal loss	1225 MWh	921 MWh	24.8 %
Top heat loss	580 MWh	597 MWh	3.0%
Storage efficiency	89.9 %	92.3 %	2.7 %
Storage cycle	1.85	1.87	1.4 %



Results

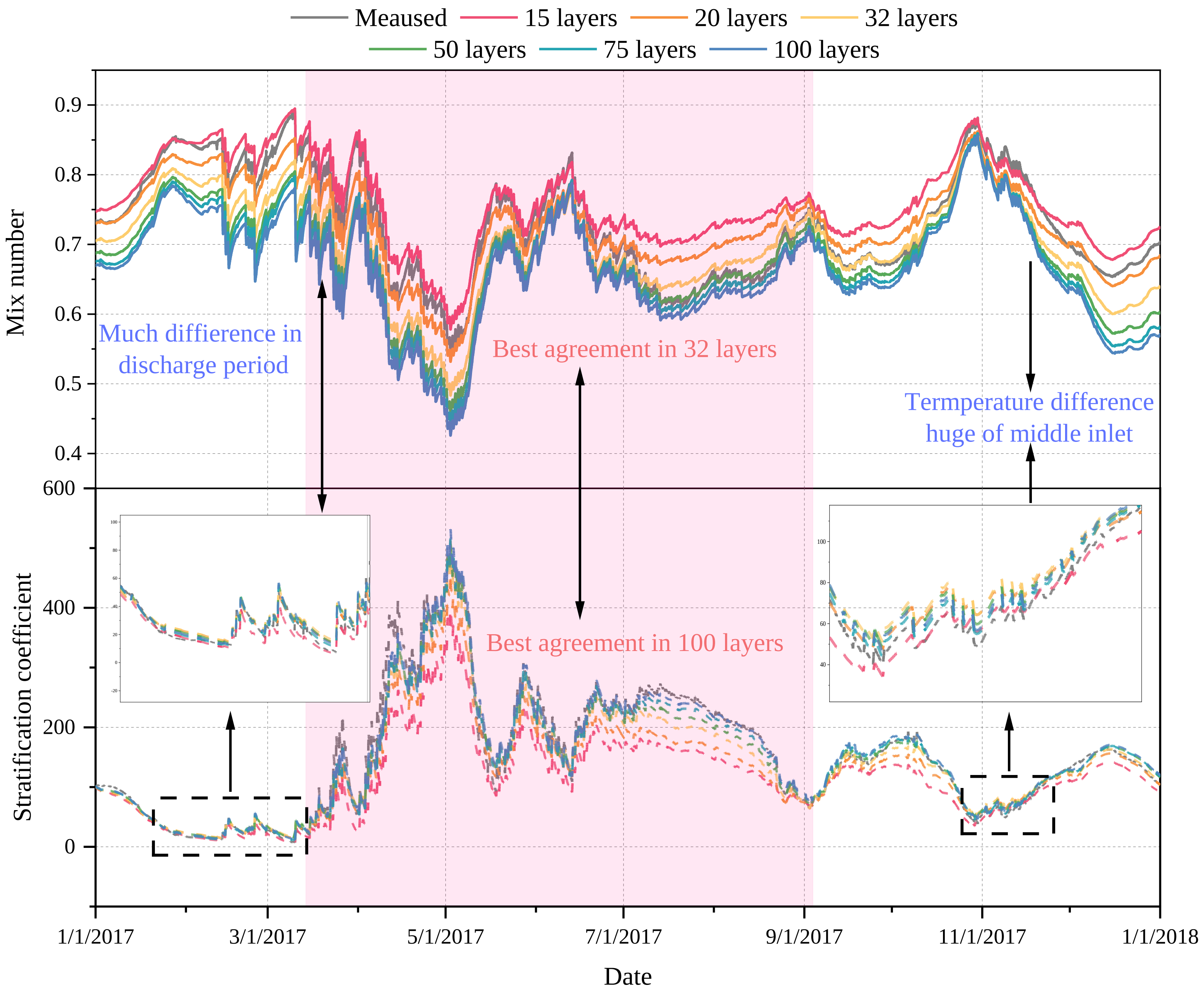


Fig.1 Mix number and stratification coefficient changes with layer number

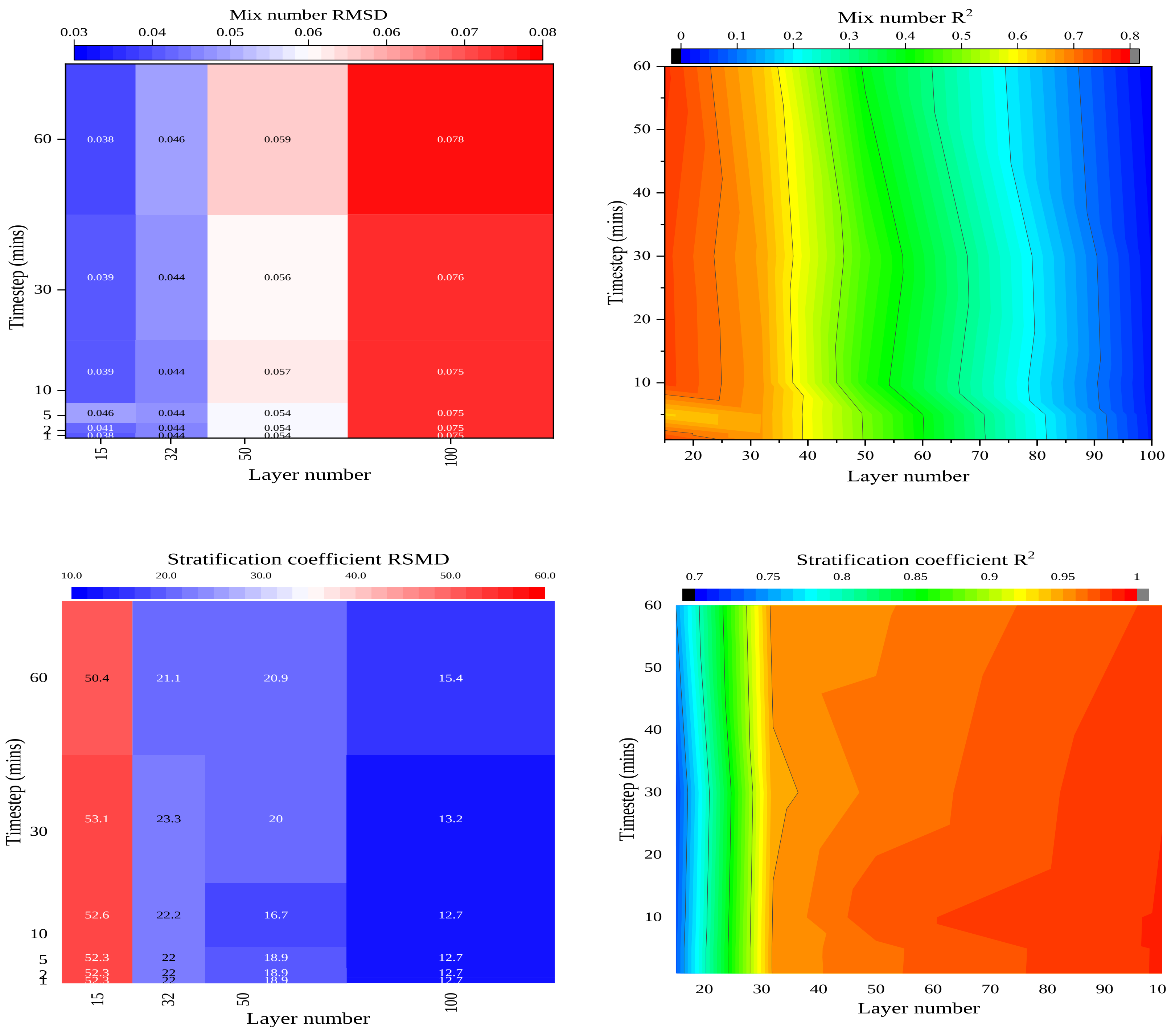


Fig.2 The coupling effect of time step and layer number on the stratification accuracy

Conclusions

This paper presents a simulation study of large-scale puddle heat storage by Trnsys and compares it with measured data from a solar district heating plant. The analysis focuses on the computational accuracy of the model for thermal stratification. In addition, the combined effects of the number of nodes and time step on the numerical diffusion are discussed. The following conclusions are obtained.

The average temperature deviation is 1.7°C, and the maximum temperature difference is 16.3°C. The maximum variation of charging energy is 69 MWh, and the maximum deviation of discharging energy does not exceed 20%. The monthly heat loss has a significant deviation and shows an opposite trend. It indicates that this model has high calculation accuracy for energy delivery but low calculation accuracy for partial temperature and heat loss.

The number of nodes has the greatest effect on the deviation of the thermal stratification calculation results, with fewer nodes predicting best for energy dispersion and more nodes predicting best for temperature dispersion.

A small number of nodes is suitable for a long time step and a large number of nodes is suitable for a short time step. 15 nodes with 60mins are most suitable for Mix number prediction and 100 nodes with 1min is most suitable for stratification coefficient prediction.