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Compressor Engineering
Refrigeration and Air Conditioning
High Performance Buildings

Model-based Optimal Control of a Building HVAC System

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PURDUE UNIVERSITY

Center for High Performance Buildings at Purdue

Outline

- Background
- Methodology
- Case Study
- Results and Discussions
- Conclusions and Future work

Background

- The energy demand from the simulation case with the optimized control strategy is 19.5% less than that from the actual building with the non-optimized control strategy in the HVAC system. (Nassif, N., Kajl, S., & Sabourin, R. (2004, June). Evolutionary algorithms for multi-objective optimization in HVAC system control strategy. In *Fuzzy Information, 2004. Processing NAFIPS'04. IEEE Annual Meeting of the* (Vol. 1, pp. 51-56). IEEE.)

Background

- Modeling effort and required computation resource are bottlenecks for on-line implementations of MPC at a large scale.
- Other optimization based control methods utilized customized physics-based models that are complex and not scalable.

Methodology

Modeling

- AHU model

$$Q_{AHU} = \dot{m}_{s,AHU} c_p (T_{s,AHU} - T_{mix})$$

$$T_{mix} = rT_{oat} + (1-r)T_{ra}$$

$$\dot{m}_{s,AHU} = \sum_{i=1}^{N_{vav}} \dot{m}_{vav}^{i}$$

$$T_{ra} = \frac{\sum_{i=1}^{N_{vav}} (\dot{m}_{vav}^{i} \cdot T_{r}^{i})}{\sum_{i=1}^{N_{vav}} \dot{m}_{vav}^{i}}$$

Methodology

Modeling

- Fan model

$$P_{fan} = a_1 \dot{m}_{s,AHU}^3 + a_2 \dot{m}_{s,AHU}^2 + a_3 \dot{m}_{s,AHU} + a_4$$

- VAV box model

$$Q_{reheat}^i = \dot{m}_{vav}^i c_p (T_{s,vav}^i - T_{s,AHU})$$

- Room air thermal response model

$$T_r = \mathrm{a}_0 + \mathrm{a}_1 \cdot T_{oat} + \mathrm{a}_2 \cdot T_{s,vav} \cdot m_{vav}$$

Methodology

Optimization formulation

- Objective

Minimize: $$Q_{total} = \frac{Q_{AHU}}{\eta} + P_{fan} + \frac{\sum_{i=1}^{N_{vav}} Q_{reheat}^{i}}{\eta}$$

- Subject to

$$T_r^{\min} \le T_r^i(t) \le T_r^{\max}$$

$$T_{s,AHU}^{\min} \le T_{s,AHU} \le T_{s,AHU}^{\max}$$

$$\dot{m}_{s,AHU} c_p (T_{s,AHU} - T_{mix}) \le Q_{capa,AHU}$$

$$\dot{m}_{vav}^i c_p (T_{s,vav}^i - T_{s,AHU}) \le Q_{capa,reheat}^i$$

Methodology

Modeling Platform and Optimization Solver

- AMPL

  A Mathematical Programming Language (AMPL) is an algebraic modeling language to describe and solve high-complexity problems for large-scale mathematical computing (i.e., large-scale optimization and scheduling-type problems).

- IPOPT

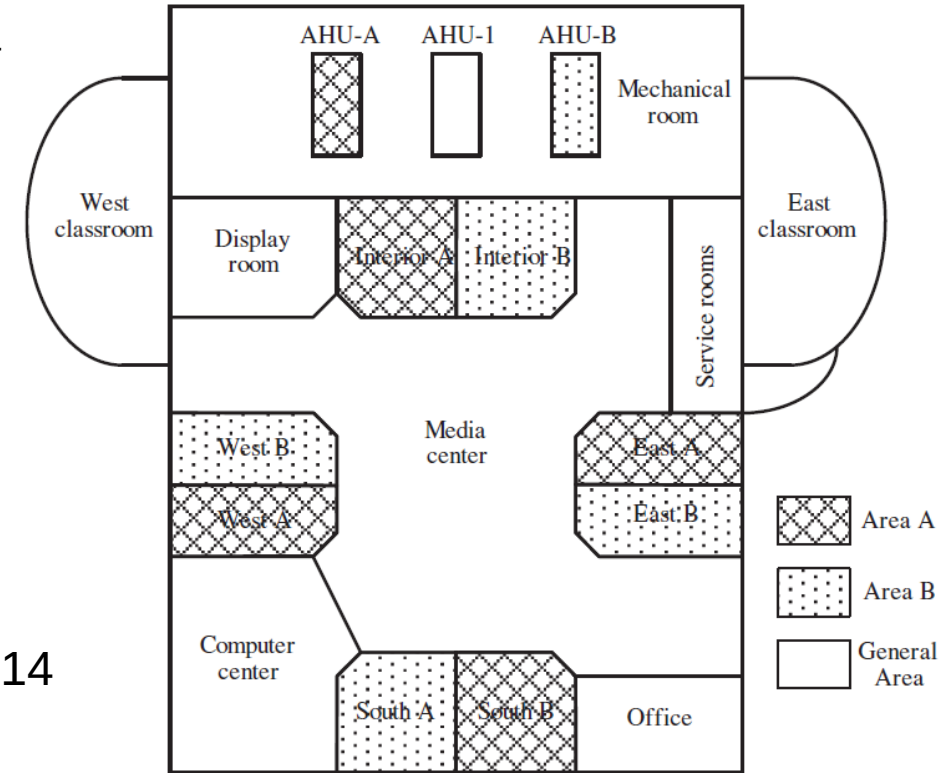
  IPOPT, short for "Interior Point OPTimizer", is a software library for large scale nonlinear optimization of continuous systems

Case Study

HVAC system-Iowa Energy Center

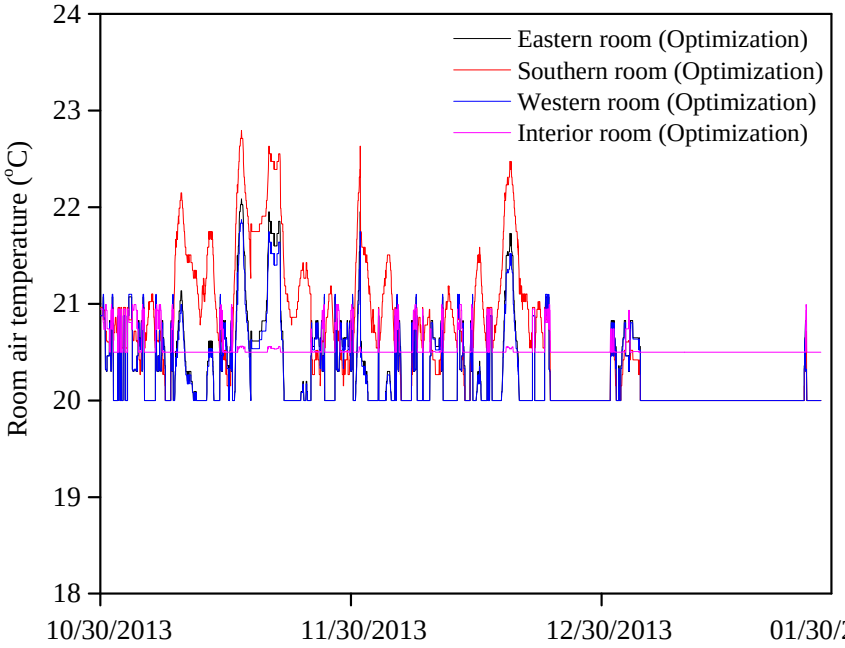
- The HVAC system B is comprised of a central AHU and an overhead ducted air distribution that terminates with four room-level VAV terminal boxes. Each test room is equipped with a pressure-independent, single-duct VAV box. Each VAV box has both a hydronic and an electric reheat coil

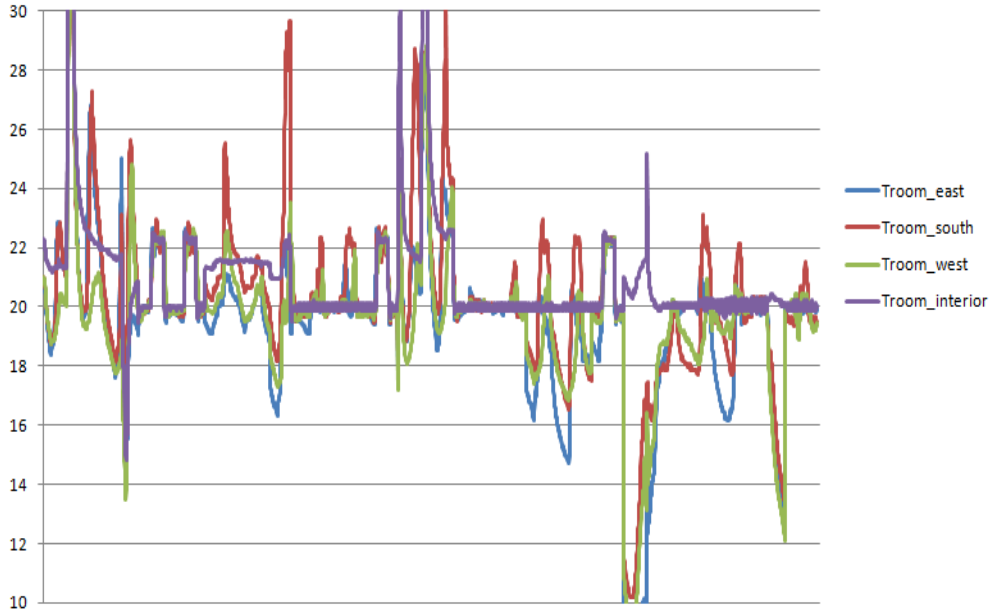
Data from Oct 30th 2013 to Jan 30th 2014



Results and Discussions

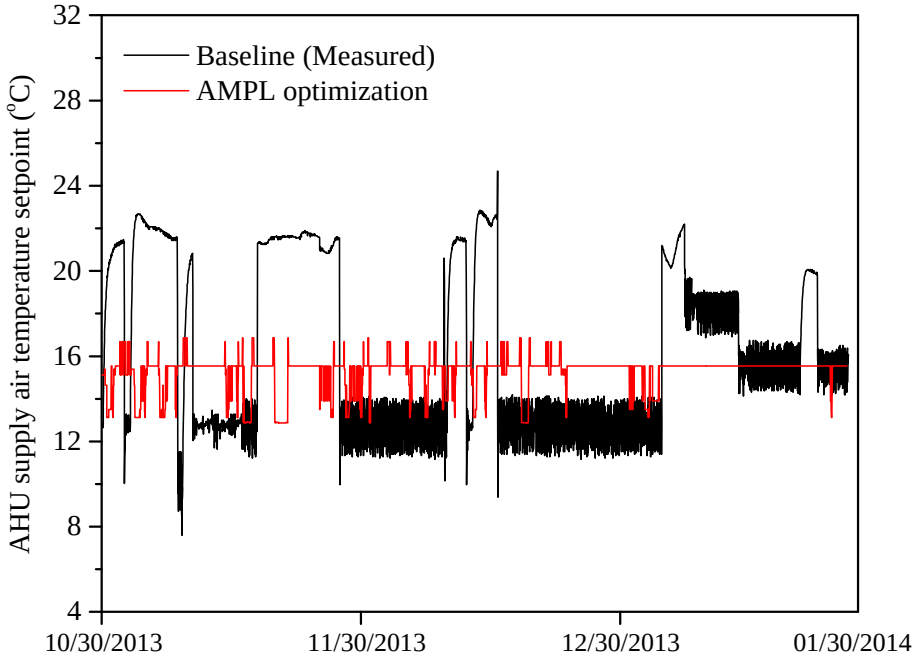
Room air temperature

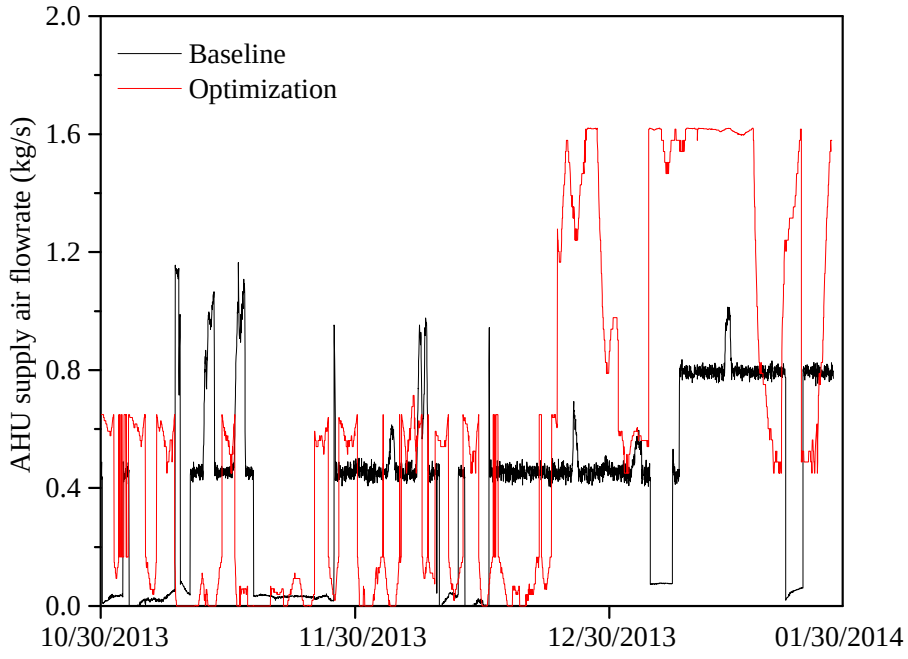




Results and Discussions

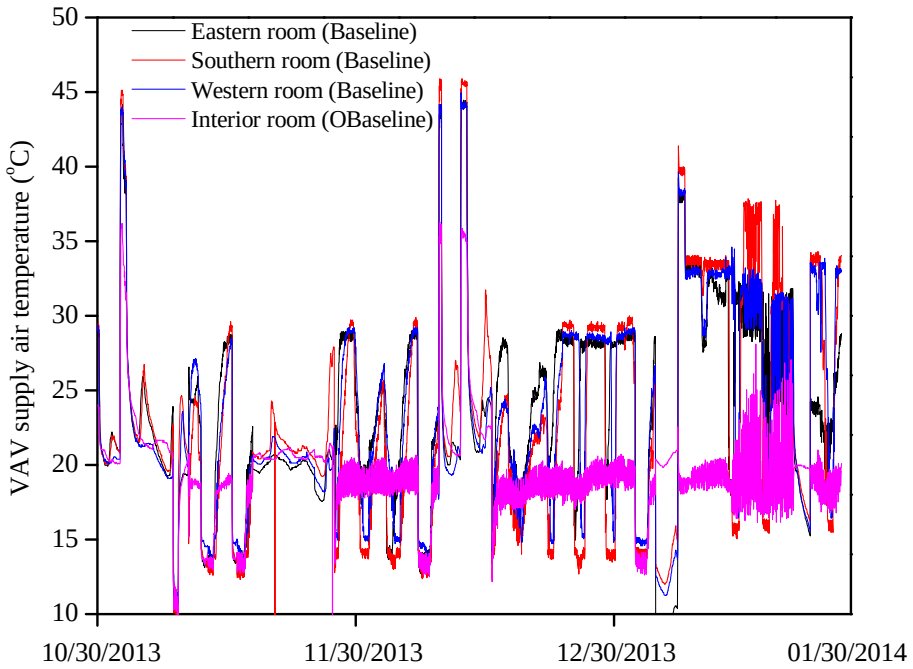
AHU supply air temperature and flow rate

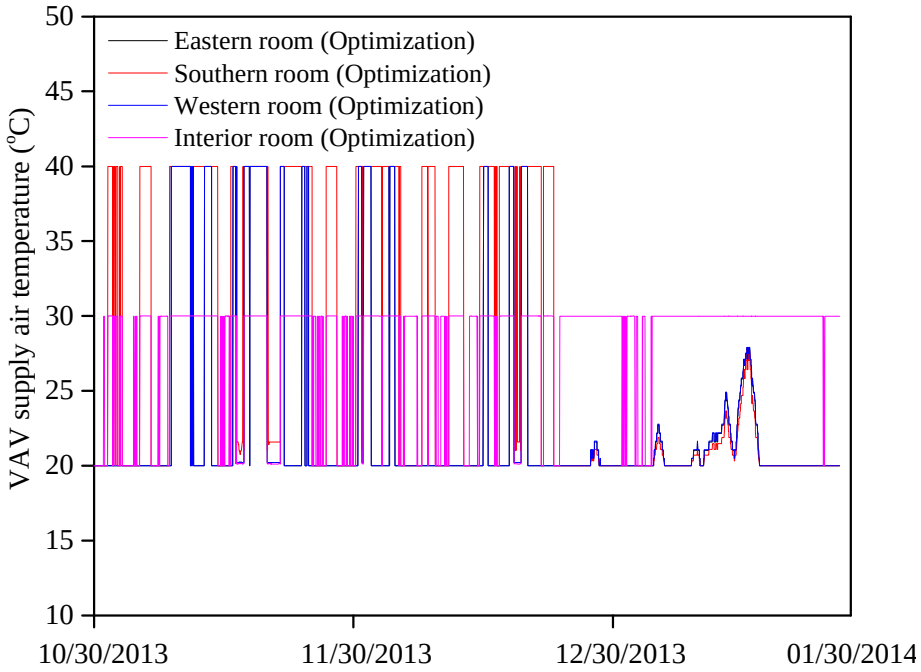




Results and Discussions

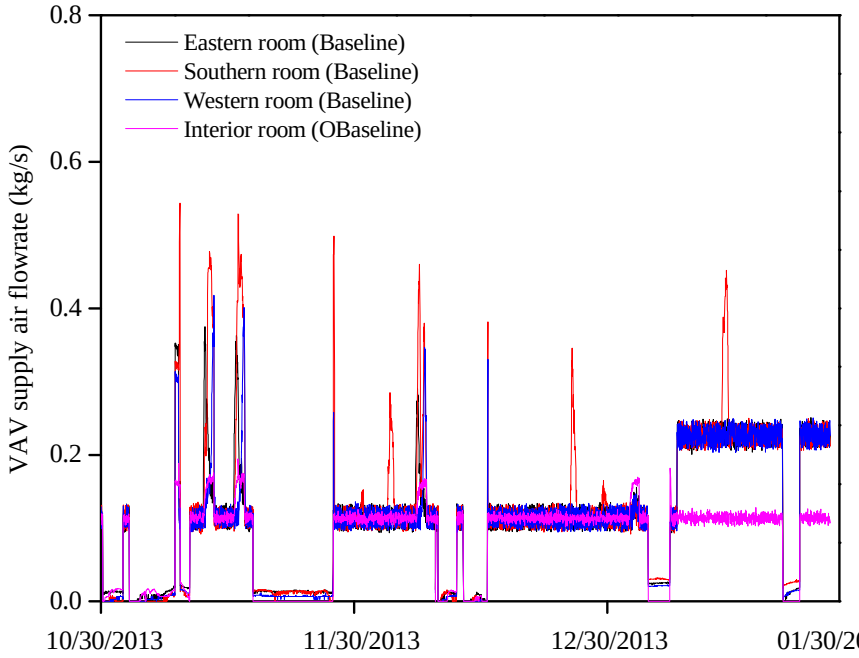
VAV supply air temperature

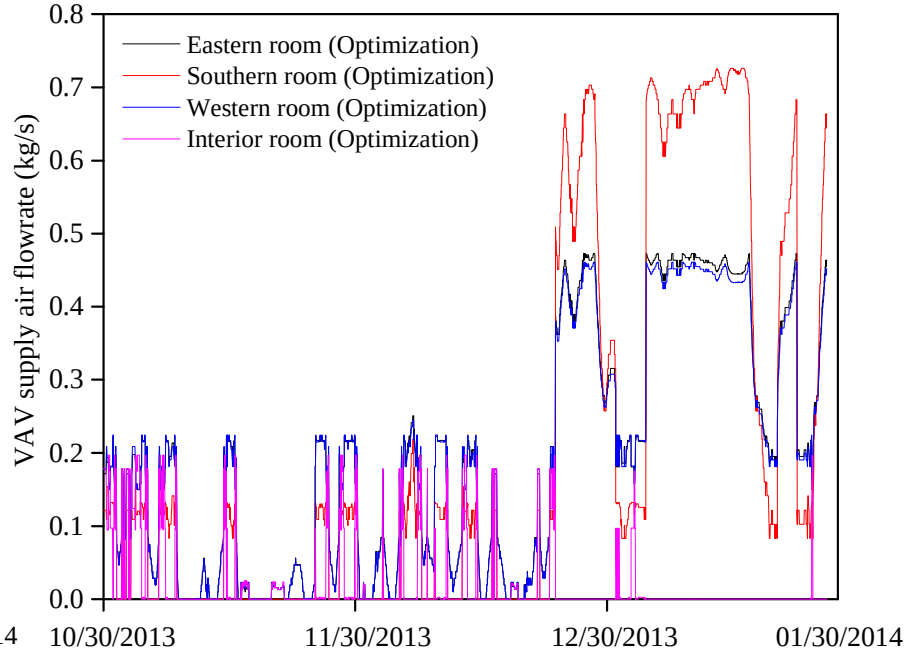




Results and Discussions

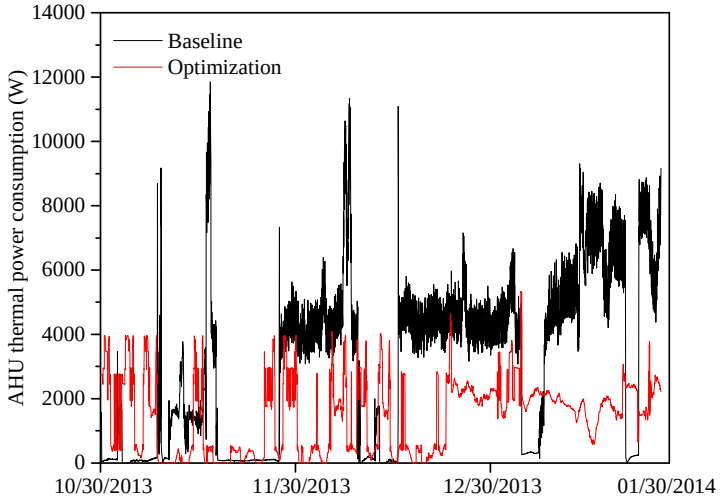
VAV supply air flow rate

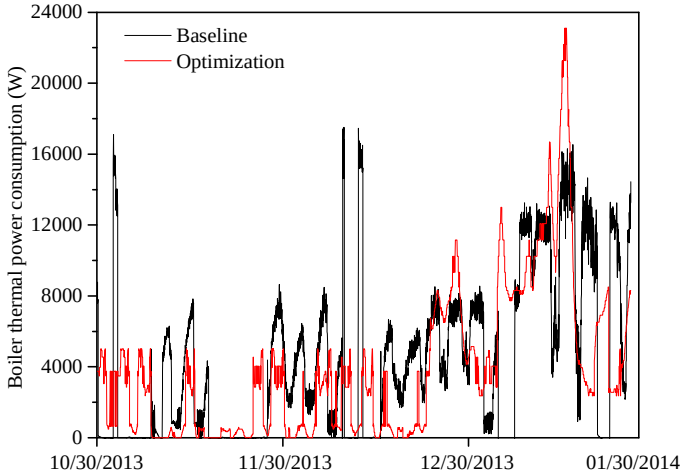


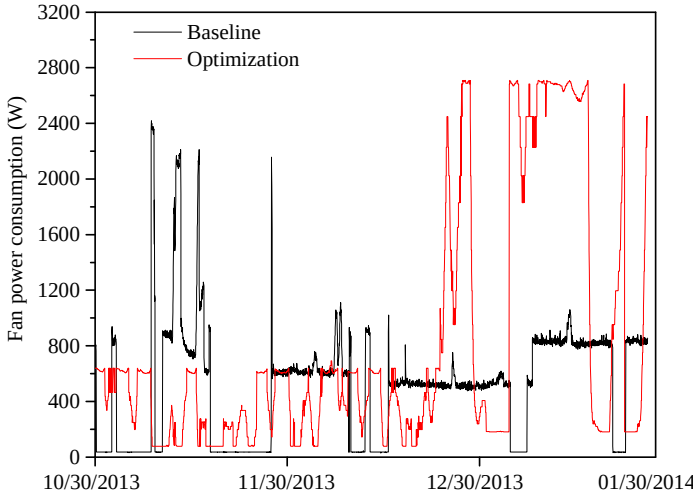


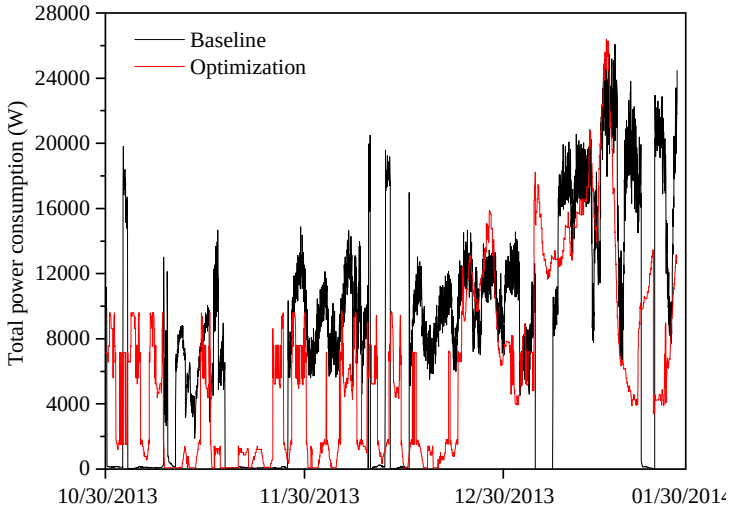
Results and Discussions

Energy consumption



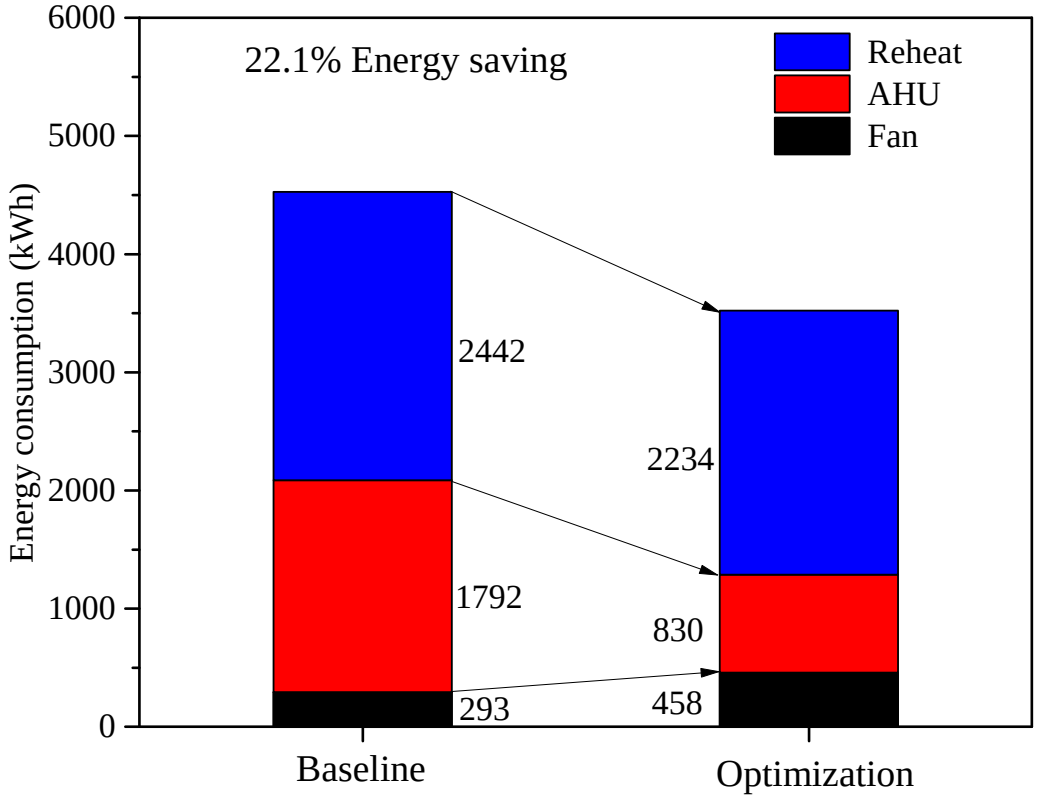






Results and Discussions

Energy consumption



Conclusions and Future work

Conclusions

- The model-based optimal control greatly saves the total energy consumption.

- The room air temperature by the model-based optimal control is more stable.

- The energy saving of model-based optimal control is realized by increasing fan supply air flow rate to reduce the AHU energy consumption and VAV box reheat coil energy consumption.

Conclusions and Future work

Future work

- The data-driven model is based on a fixed historical data set. It is better to use a moving window to incorporate HVAC operation changes.

- Additional optimal control in the cooling mode will be conducted to analyze the annual energy performance.

- Demonstration and implementation of the proposed optimal control in the Building Energy Management System in a real building.

Thanks!

Any questions?