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Smart Geotherm

Tips and tricks for cost function of complex building optimal controllers

Damien Picard[1]
Lieve Helsen[1]

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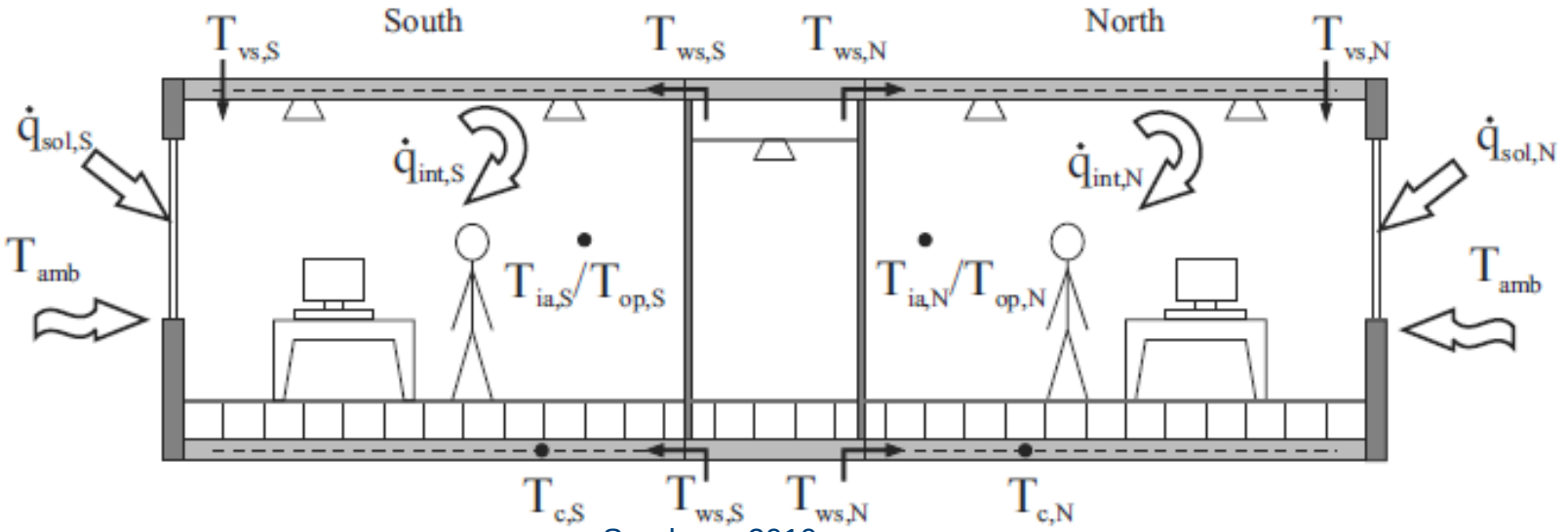
[1] KU Leuven, Department of Mechanical Engineering, Division of Applied Mechanics and Energy Conversion

Description of system

Building

- Three zones: north, south, corridor
- TABS
- VAV for north and south zone
- Internal gains
- Realistic parameters



Sourbron, 2010

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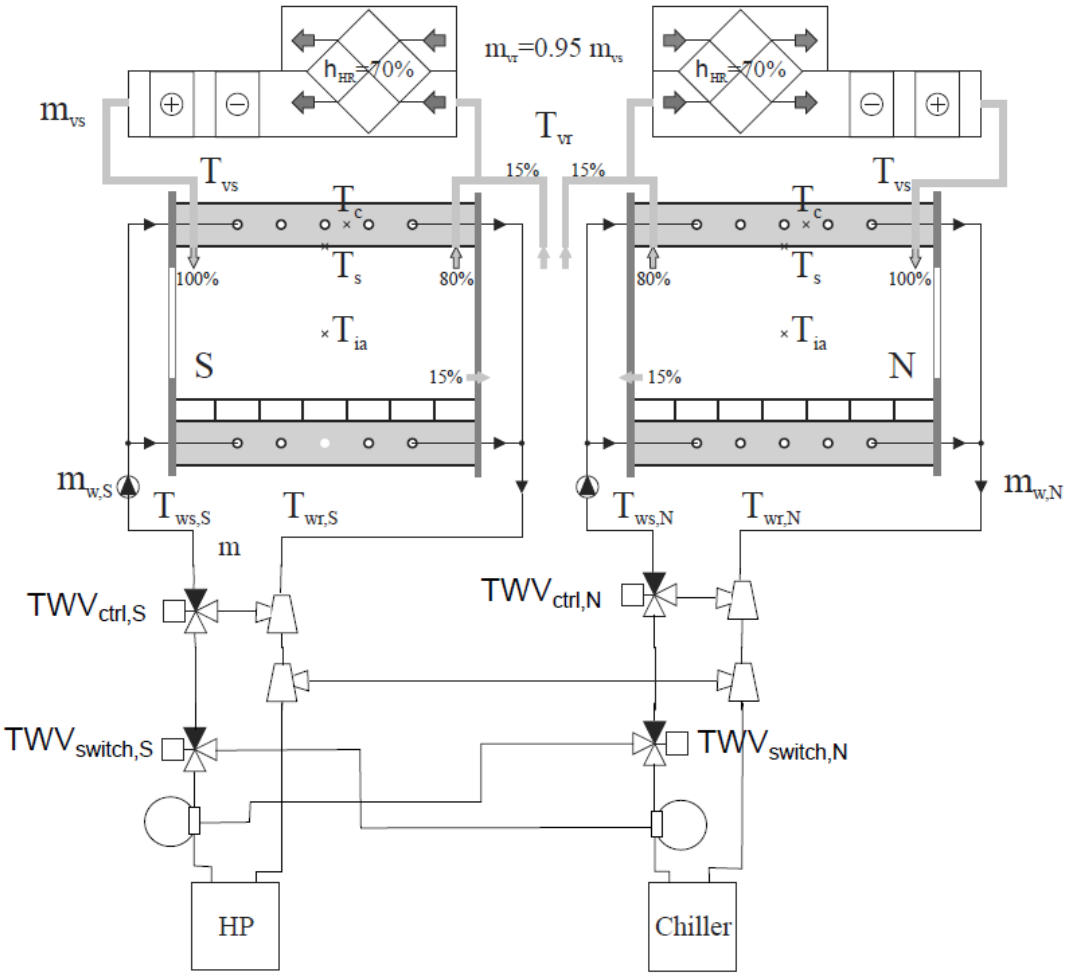
Description of system

Ventilation

- VAV
  - heating coil fed by gas-boiler
  - cooling coil fed by LT-chiller
  - heat recovery with by-pass
- Hygienic mass flow rate
- No latent heat or CO2

Heating system

- Air-coupled heat pump for heating
- High temperature chiller
- Variable speed pumps
- Three-way valves



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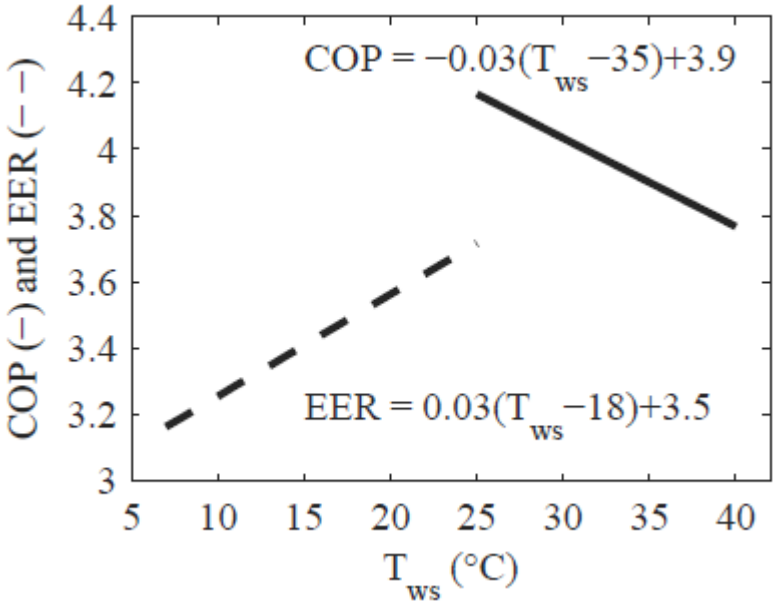
Description of system

Heat and cold production

- No dynamics
- Gas boiler (η = 0.95), LT-chiller (EER = 3)
- Heat pump and HT-chiller with variable COP / EER (based on Eurovent data)



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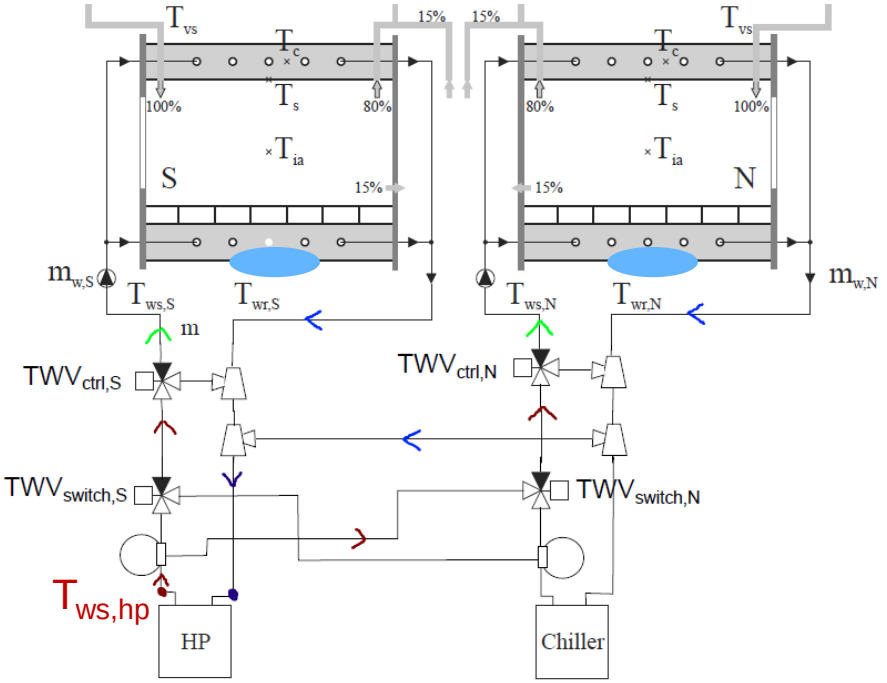
Non-linearities of cost function

TABS and heat pump

- Inputs
  - HP supply temperature $T_{ws,hp}$
  - Zones supply temperature $T_{ws,z}$
  - Zones mass flow rate m_{zone}
- States
  - Water in tabs ($T_{ws,hp}$)

$$m_{vol} c_{p,w} \frac{\mathrm{d}T^N_{vol}}{\mathrm{d}t} = \dot{m}^N_z c_{p,w} \left(T^N_{ws,z} - T^N_{vol}\right) + G^N \left(T^N_{emb} - T^N_{vol}\right)$$



- Cost function

$$P_{el,hp} = \frac{Q}{COP} = \frac{c_{p,w} \dot{m}_{hp} \left(T_{wr,hp} - T_{ws,hp}\right)}{-0.03 \left(T_{ws,hp} - (35 + 273.15)\right) + 3.9}$$

with

$$\dot{m}_{hp} = \dot{m}^N_{hp} + \dot{m}^S_{hp}$$

$$\dot{m}^N_{hp} = \dot{m}^N_{\text{zone}} \frac{T^N_{ws,z} - T^N_{vol}}{T^N_{ws,hp} - T^N_{vol}}$$

$$\dot{m}^S_{hp} = \dot{m}^S_{\text{zone}} \frac{T^S_{ws,z} - T^S_{vol}}{T^S_{ws,hp} - T^S_{vol}}$$

$$T_{wr,hp} = \frac{\dot{m}^S_{hp}}{\dot{m}_{hp}} T^S_{vol} + \frac{\dot{m}^N_{hp}}{\dot{m}_{hp}} T^N_{vol}$$

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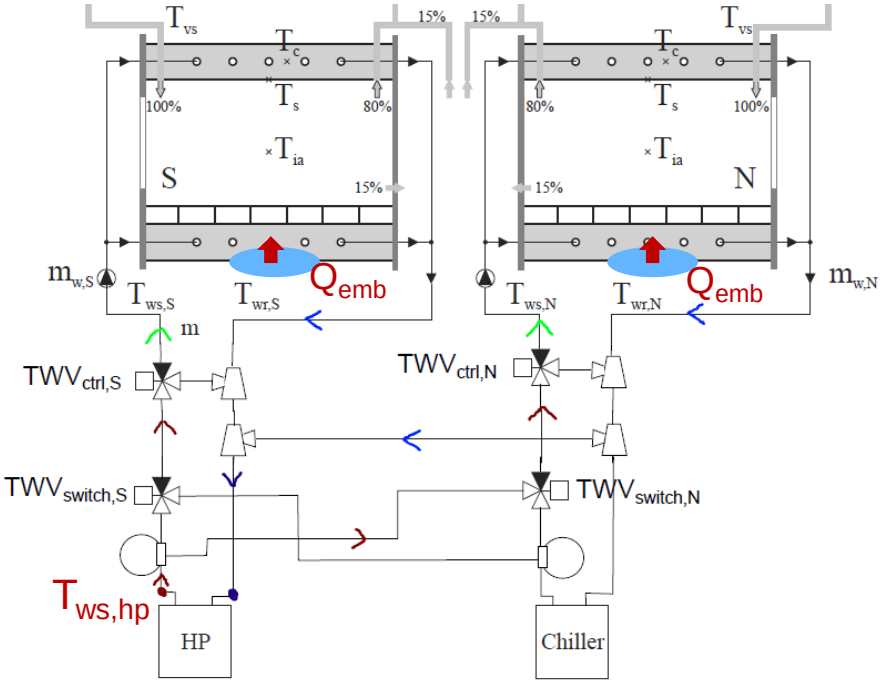
Non-linearities of cost function

TABS and heat pump

- optimize Q_{emb} instead of $m\Delta T$ ➔ $Q_{emb} \approx Q_{hp}$
- Use heating curve for $T_{ws,hp}$ + *modes*
- Neglect dynamics of water (small time constant)

- Cost function

$$P_{el,hp} = \frac{Q^N_{emb} + Q^S_{emb}}{-0.03\left(T_{ws,hp} - (35 + 273.15)\right) + 3.9}$$



+ Linear cost function
+ Good approximation of production cost
+ For $Q_{emb} \to 0,\ \dot{m}_{zone} \to 0$

- Non-optimal *mode*, $T_{ws,hp}$ and $\dot{m}_{zone}$
- extra PID or static relationship: $\dot{m}_{zone} = \frac{Q_{emb}}{c_{p,w,}}\left(T_{ws,hp} - T_{emb} - \frac{Q_{emb}}{G}\right)^{-1}$

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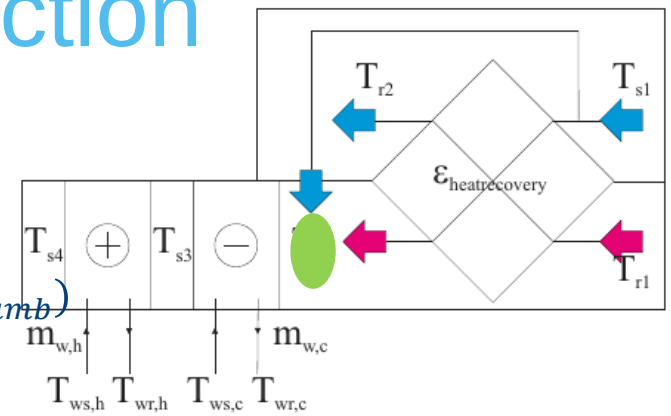
Non-linearities of cost function

Ventilation



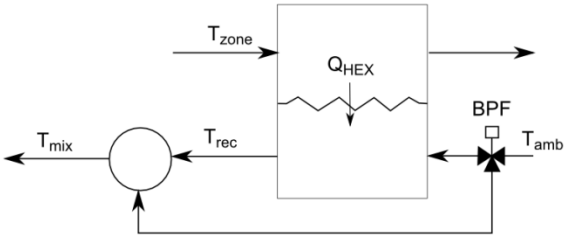
- Heat recovery (assuming constant ε for HEX):

$$T_{rec} = T_{amb} + \epsilon(T_{zone} - T_{amb})$$

- Mixed air using by-pass

$$V_{mix}\rho_a c_{p,a}\frac{\mathrm{d}T^N_{mix}}{\mathrm{d}t} = \dot{m}^N_{vent}c_{p,a}\left(-T^N_{mix} + \epsilon\ \mathrm{BPF}^N\left(T_{amb} - T^N_{zone}\right) + (1-\epsilon)T_{amb} + \epsilon T^N_{zone}\right)$$

$$\mathrm{BPF}^N = \frac{T^N_{vent,set} - \epsilon\left(T^N_{zone} - T_{amb}\right) - T_{amb}}{\epsilon\left(T_{amb} - T^N_{zone}\right)} \quad \text{s.t.} \quad 0 \le \mathrm{BPF}^N \le 1$$



- Additional power by heating or cooling coil

$$Q = \dot{m}^N_{vent}c_{p,a}\left(T^N_{vent,set} - T^N_{mix}\right)$$

- Cost function

$$P_{Fuel} = \eta Q \quad \text{or} \quad P_{el} = \frac{Q}{EER}$$

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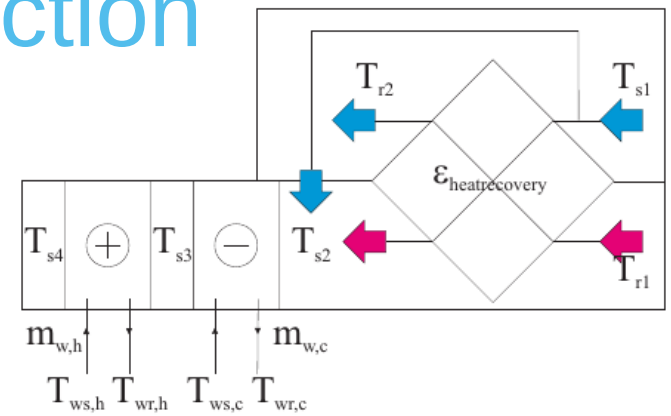
Non-linearities of cost function

Ventilation

- Neglect air dynamics
- Use min and max function to guess BPF stand:

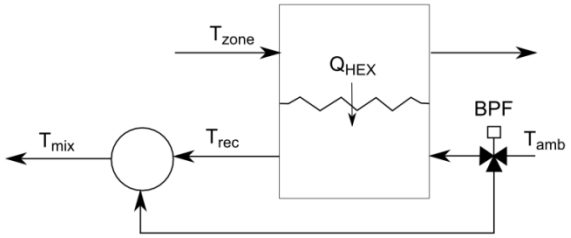


$$P^N_{\text{fuel,boi}} = \max\left(\frac{1}{\eta}\,\dot{m}^N_{vent} c_{p,a}\left(T^N_{vent,set} - \max\left((1-\epsilon)T_{amb} + \epsilon T^N_{zone}\ ,\ T_{amb}\right)\right)\ ,\ 0\right)$$

$$\text{s.t.}\quad \frac{Q_{heaUnit,nom}}{\eta} \geq P^N_{\text{fuel,boi}}$$

$$P^N_{\text{el,chi LT}} = \max\left(\frac{1}{EER}\,\dot{m}^N_{vent} c_{p,a}\left(\min\left((1-\epsilon)T_{amb} + \epsilon T^N_{zone}\ ,\ T_{amb}\right) - T^N_{vent,set}\right)\ ,\ 0\right)$$

$$\text{s.t.}\quad \frac{Q_{cooUnit,nom}}{EER} \geq P^N_{\text{el,chi LT}}$$



→ Non convex, but:

- if heating, mostly $T_{amb} < T_{rec}$ → Use heat recovery
- if cooling, mostly $T_{amb} < T_{rec}$ → Don't use heat recovery

- Cost function: $P_{fuel,boi} = \max\left(\frac{1}{\eta}\,\dot{m}_{vent} c_{p,a}\left(T_{vent,set} - (1-\epsilon)T_{amb} - \epsilon T_{zone}\right), 0\right)$

$$P_{el,chi\ LT} = \max\left(\frac{1}{EER}\,\dot{m}_{vent} c_{p,a}\left(T_{amb} - T_{vent,set}\right), 0\right)$$

- Notice: if $0 < BPF < 1$ → $P_{fuel} = P_{el} = 0$

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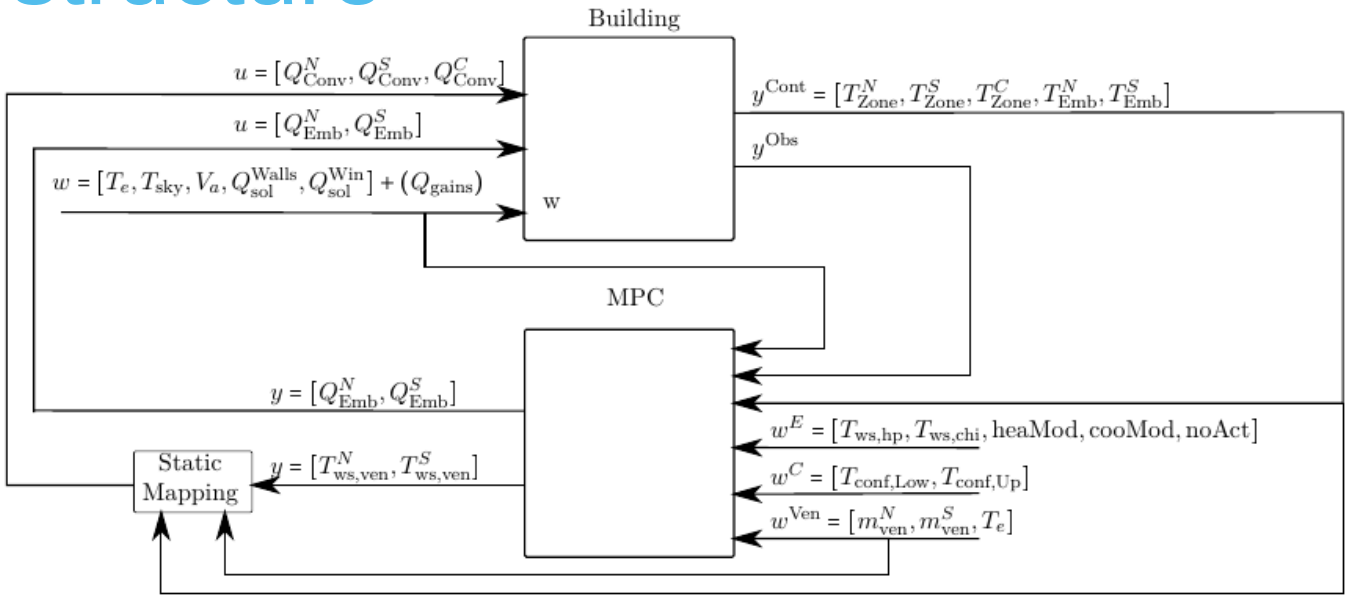
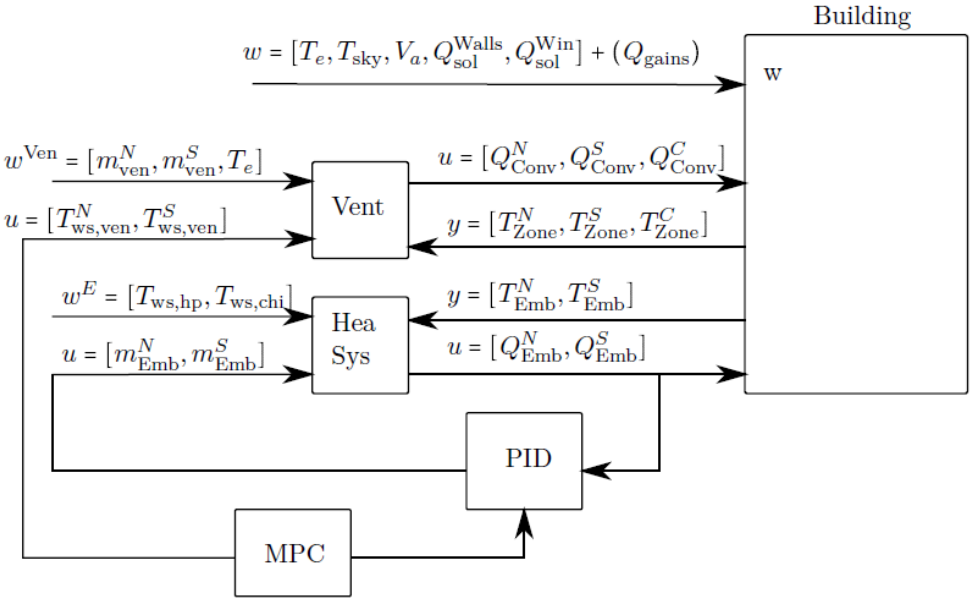
MPC structure

1)



2)



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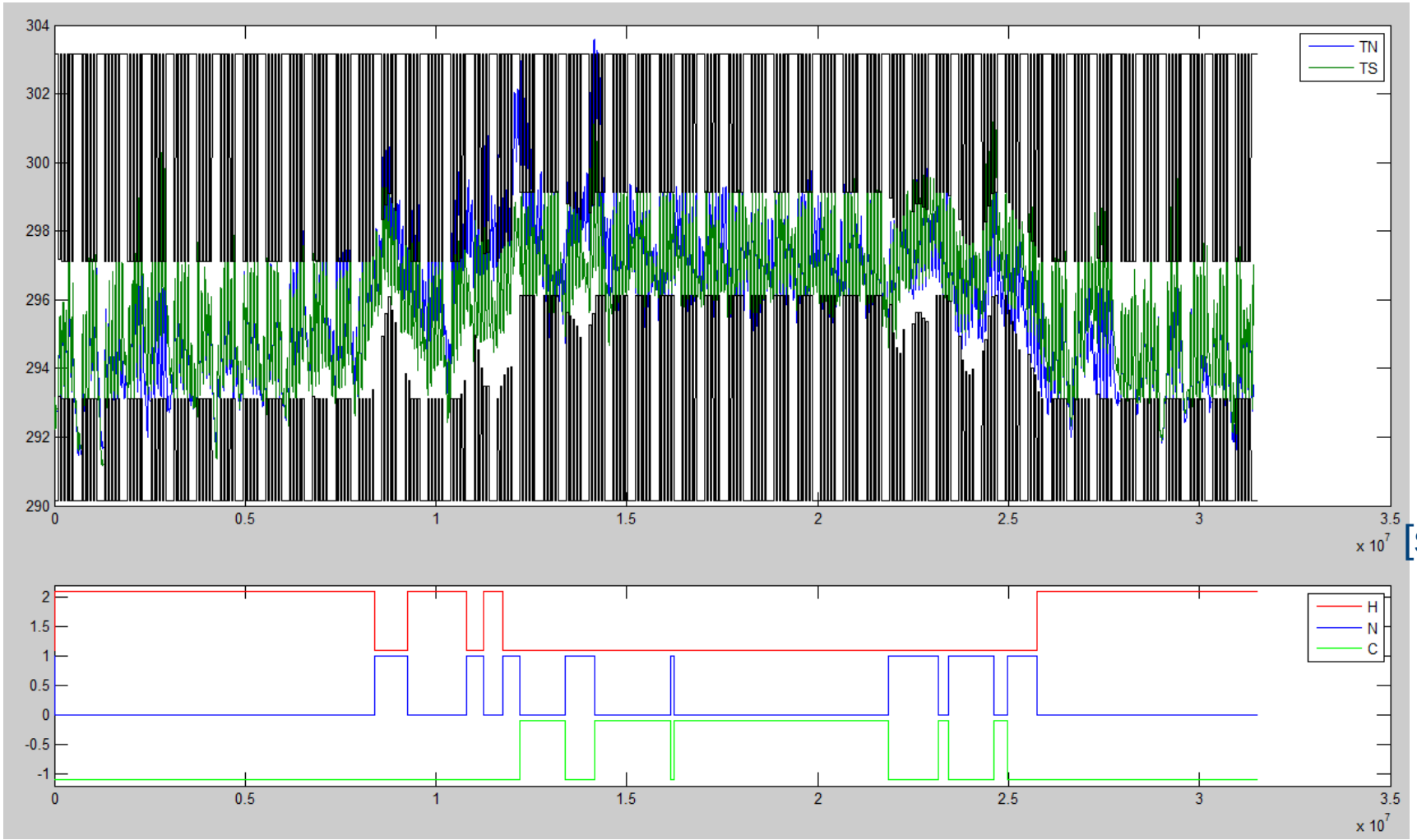
MPC results



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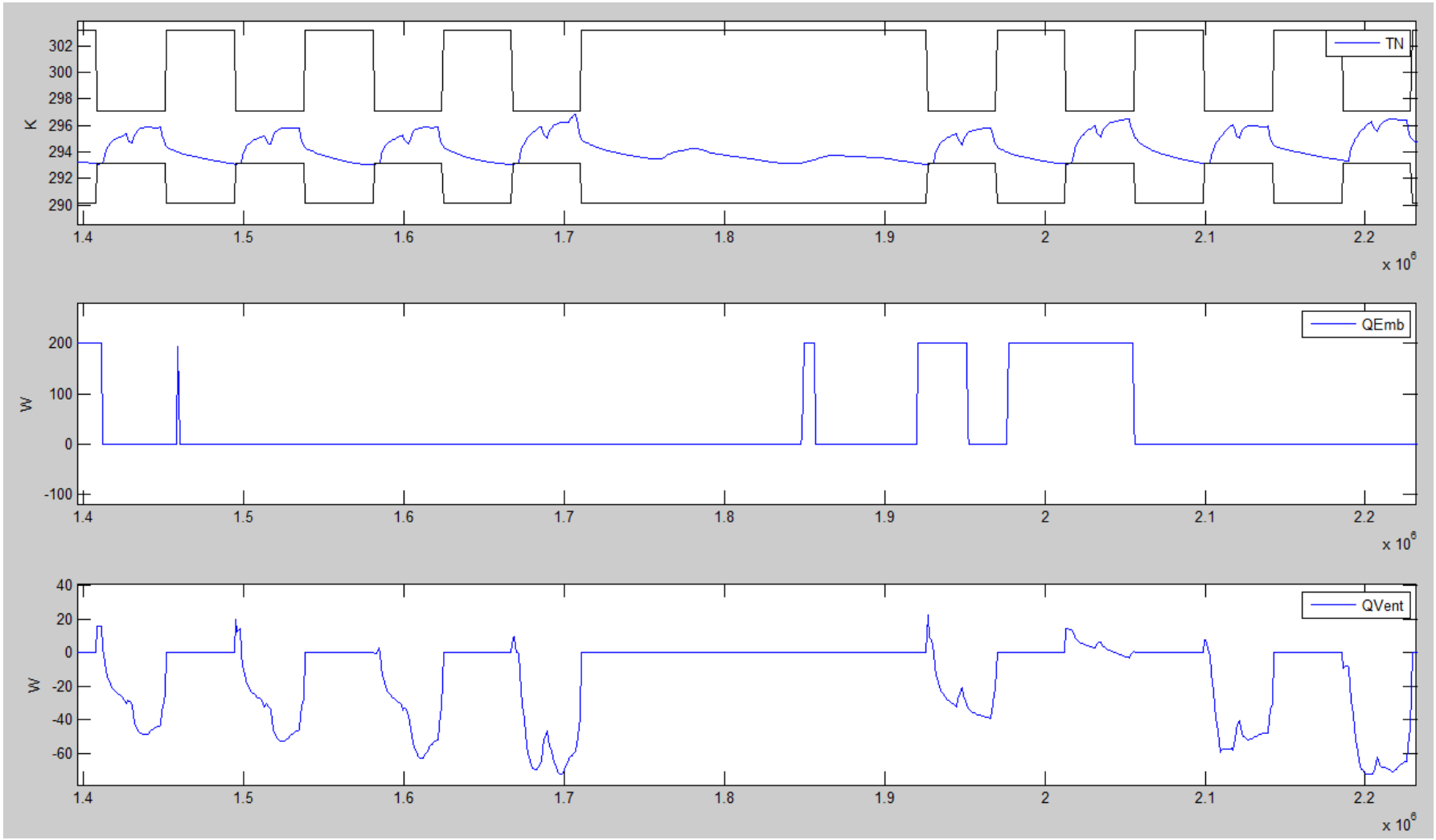
MPC results



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Conclusion

- Strong non-linearities in HVAC
- Hybrid systems require more accurate cost function
- Good approximations based on physical insights for ventilation
- Hierarchical MPC

- Loss of optimality due to non-optimal $\dot{m}, \mathrm{T}_{\mathrm{ws,hp}}, \mathrm{T}_{\mathrm{ws,chi}}$, modes

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Questions?