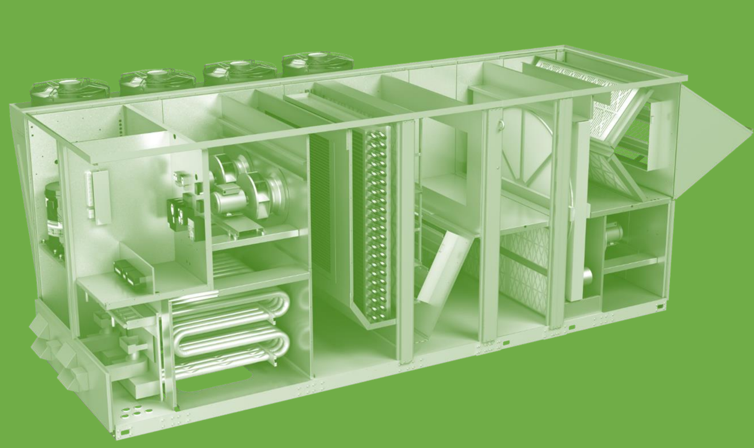

Enhancing energy efficiency in buildings with model predictive control

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Context

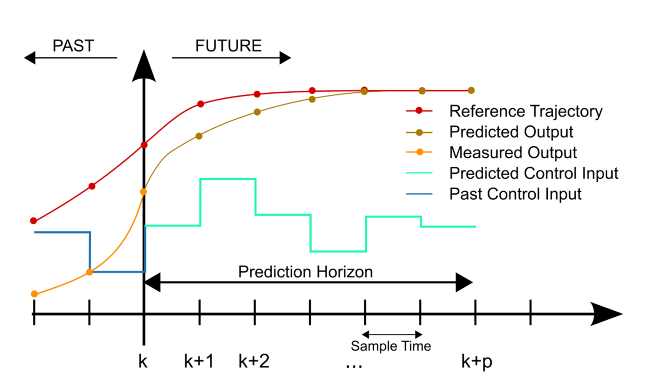
- For economical and environmental purposes, considerable research efforts have been devoted to diminish our overall energy consumption.
- Buildings have been found to contribute to approximately 41% of the energy consumption in the United States.
- There are uncertainties on how to increase the energy efficiency in buildings without replacing mechanical systems.

Objectives:

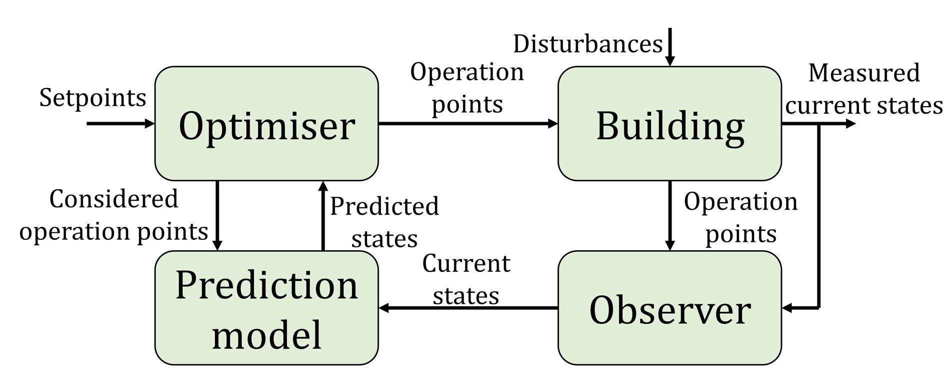
1. Develop a control strategy for heating, ventilation, and air conditioning (HVAC) systems to increase the energy efficiency of buildings while providing thermal comfort.
2. Compare the performance of the obtained controller with conventional control strategies.

Model predictive control (MPC)

- Intelligence acting on one or several **manipulated variables** (e.g., hot and cold air flow rates) to reach setpoints of **controlled variables** (e.g., air temperature).
- Prediction model of the dynamics of the controlled system to evaluate its future behaviours depending on the considered operation points.
- Optimisation process to find best operation points based on objectives such as reducing the energy consumption.



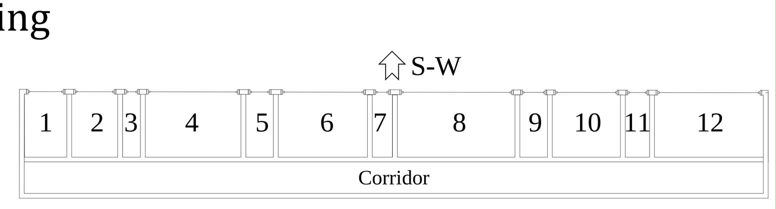
Principle of a model predictive controller.
(Credit: Martin Behrendt [CC BY-SA (https://creativecommons.org/licenses/by-sa/3.0)])



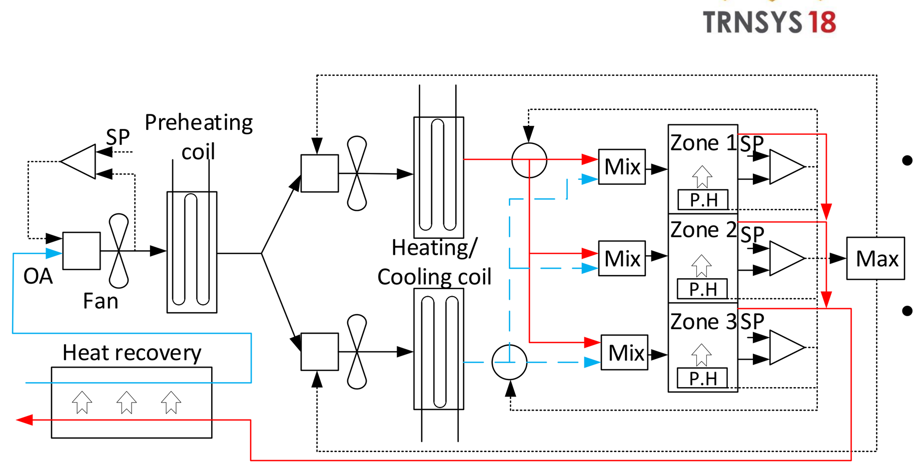
Schematic representation of an MPC.

Test case

- 12 occupied rooms of an institutional building located in Quebec City, Canada.
- Modeled in TRNSYS.



Top-view plan of the disposition of the rooms.



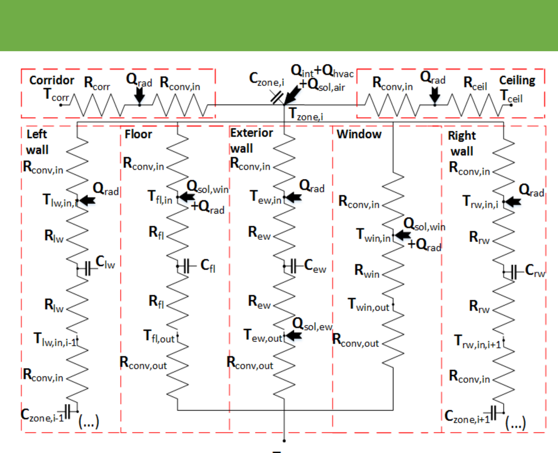
Representation of the HVAC system and control scheme.

- Heating and cooling provided through ventilation and peripheral heaters.
- Current control based on highest needs using proportional (PI) controllers.

Methodology

1. Produce prediction models to represent:
   a) The thermal behaviours of the test case building;
   b) The impact of the decisions on the HVAC system.

$$\dot{W}_{cool} = \frac{\dot{m}_c c_p \left(T_{ca,i} - T_{ca,o}\right)}{COP_R} \qquad \dot{W}_{heat} = \frac{\dot{m}_h c_p \left(T_{ha,o} - T_{ha,i}\right)}{\eta_f}$$



Thermal network for one room.

2. Develop an optimisation process to find the best operation points.

$$f_{cost} = w_{comfort}\sum_{j=1}^{H_p}\sum_{i=1}^{N_{zone}}\left\{\Delta T_{under,i,j} + \Delta T_{over,i,j}\right\} + w_{energy}\sum_{j=1}^{H_p}\dot{W}_{HVAC,j}$$

3. Test the MPC on the numerical model of the test case.
4. Analyse energy efficiency performance results.
5. Produce a novel design tool for engineers to estimate performance based on the defined optimisation process.

Results

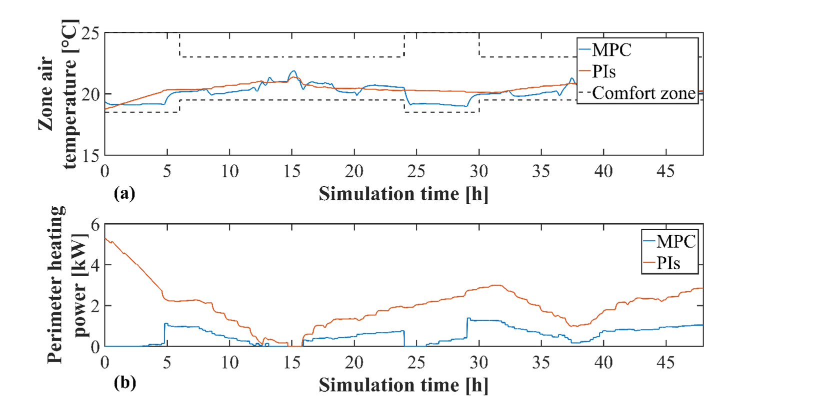
- 48-hour simulations in summer and winter.

Energy consumption of the HVAC system as a function of the controller.

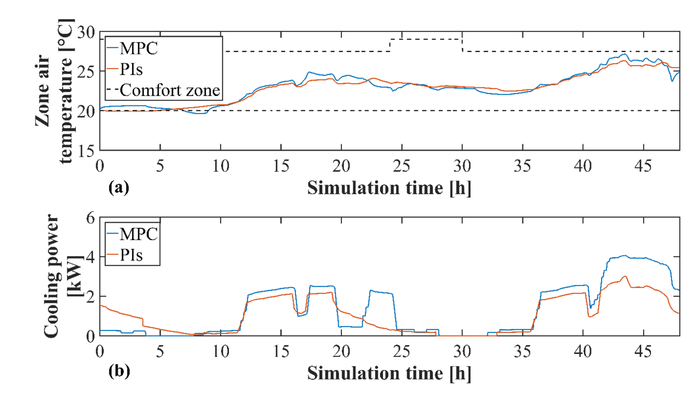
Control strategy	Energy consumption [kWh/m²-day]					
	Fans		Heating		Cooling	
	48 h in summer	48 h in winter	48 h in summer	48 h in winter	48 h in summer	48 h in winter
Traditional controller	0.090	0.080	0	0.558	0.092	0.007
MPC	0.077	0.057	0.011	0.308	0.091	0.009
Savings by MPC	14.5%	28.8%	-	44.8%	1.1%	-

Highlights

- Overall energy consumption reduced from 0.826 to 0.551 kWh/(m^2-day).
- **Energy savings of ~33%.**
- Smaller indoor air temperature with MPC in winter.



(a) Zone 10 air temperature and (b) perimeter heating power consumption during the simulated time in winter.



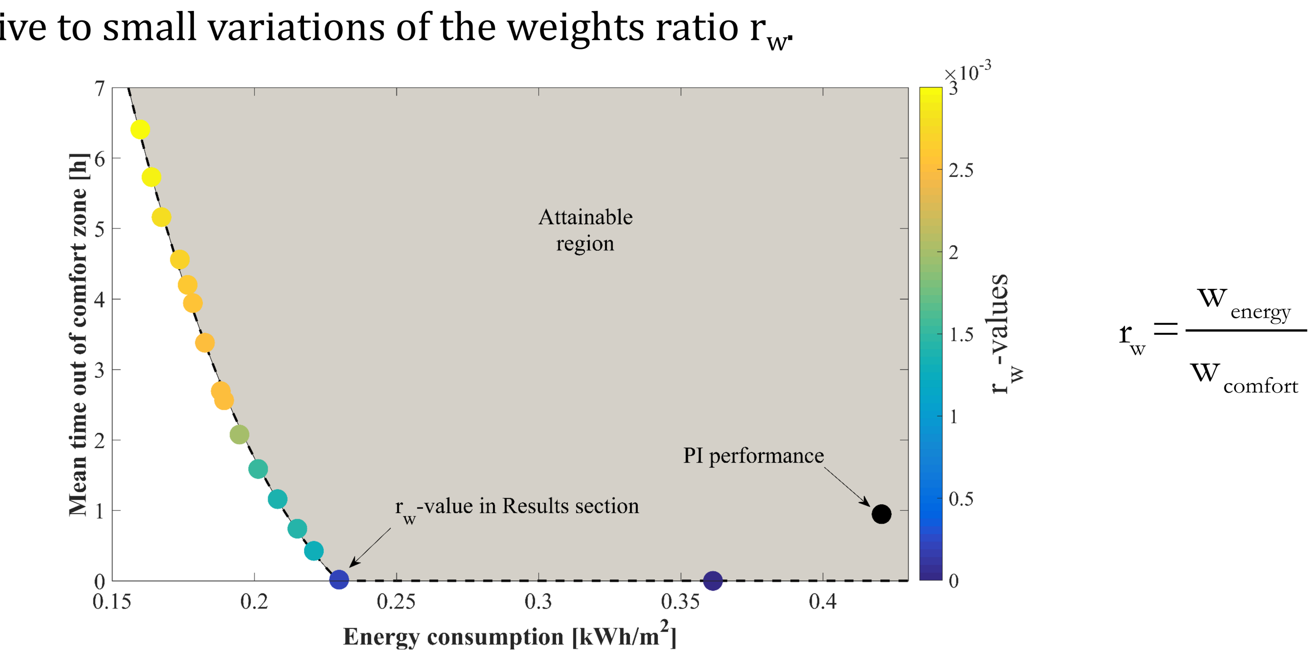
(a) Zone 10 air temperature and (b) rooftop unit cooling power consumption during the simulated time in summer.

- Better use of flexible comfort zone with MPC.
- Overall time outside of comfort zone reduced by 95.1 % with MPC.

Design tool

Highlights

- Provide information to design the optimisation process depending on objectives.
- Relative importance between energy consumption and comfort impacts MPC.
- Sharp increase in time out of comfort zone at r_w-value around 0.0002.
- Designer should be careful if energy consumption is the main objective.
- MPC sensitive to small variations of the weights ratio r_w.



$$r_w = \frac{w_{energy}}{w_{comfort}}$$

Optimized energy consumption and thermal comfort as a function of the relative importance given to each objective.

Conclusions

- A model predictive controller has been developed and implemented in a 12-room institutional building.
- It successfully increased the energy efficiency of the HVAC system by reducing its energy consumption by ~33% during simulated time.
- A design tool has been produced to facilitate the work of control engineers in enhancing the energy efficiency of buildings with better control.
- The development of prediction models in buildings contexts is complex. Future work could include the use of methods such as artificial intelligence to facilitate this process.

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