Using Decision Making to Improve Energy Efficiency of Buildings

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Introduction

Building heating and cooling accounts for nearly 18-24% of all energy usage.

Building energy management can reduce both its operating costs and its carbon footprint. In this project, we propose a fully autonomous decision-making system called Autonomous Thermal Control System to optimally control a building heating system. Our main goal is to not expend energy on heating or cooling a space in the building if there is no occupant currently present.

HVAC System
- Has a single temperature setpoint
- Ignores activity pattern and thermal comfort.
- Every individual experiences the same environment

Autonomous Thermal Control System
- Saves energy by determining activity pattern and thermal comfort of residents of a building
- Leads to individual thermal environments

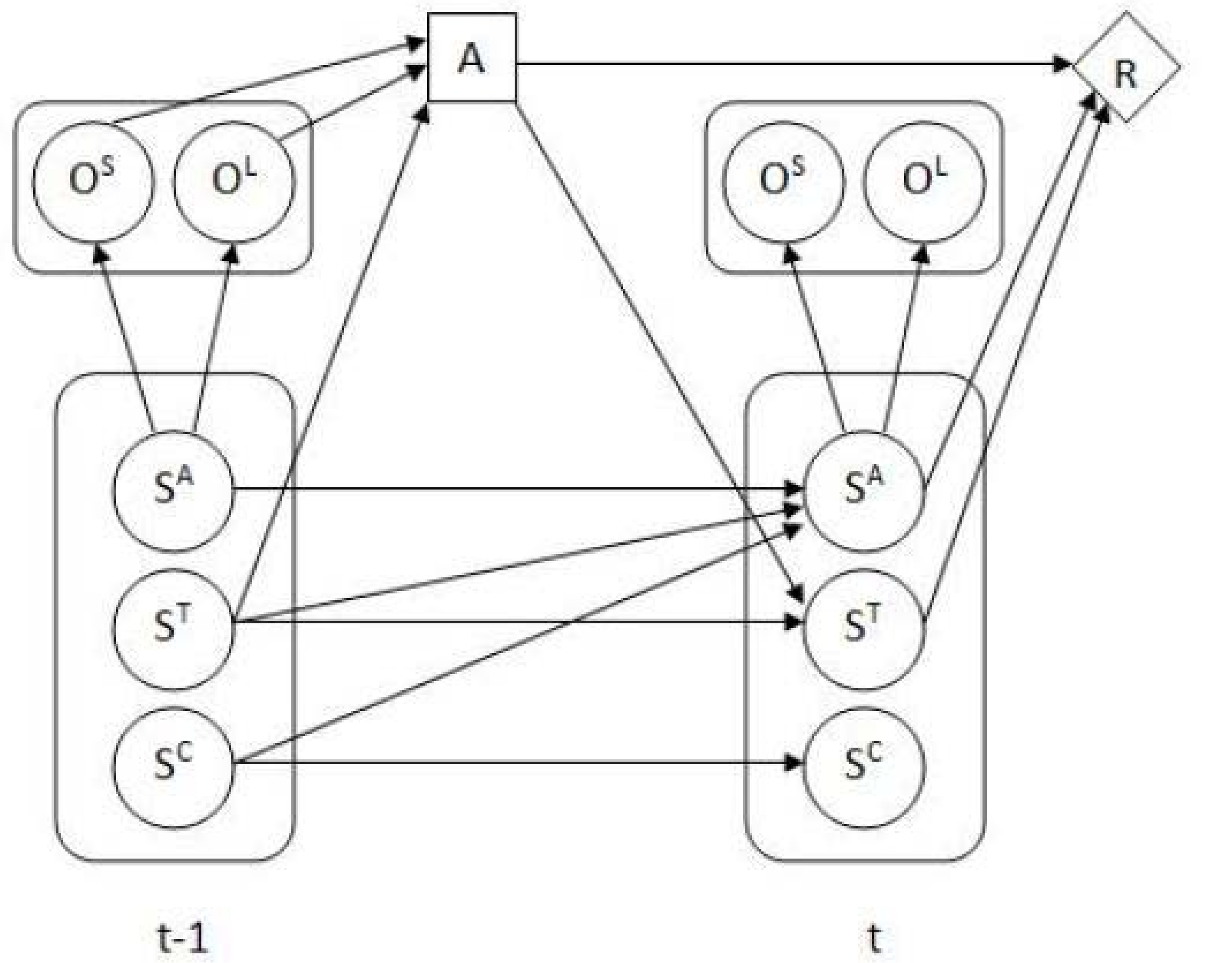
Model

The state variables are:
- The activity in a room (S^A)
- Indoor temperature (S^T)
- Half-hour interval of time within a week (S^C)

The domains of these state variables are defined as follows:
- Dom(S^A) = {Active, Inactive}
- Dom(S^T) = {10, 10:5, 11, ..., 29, 29:5, 30}
- Dom(S^C) = {0:30, 1:00, ..., 167:30, 168:00}

Since activity is a hidden variable, the belief of being in a certain activity state is updated based on the value of two observation variables:
- The sound level (O^S)
- The light levels (O^L)

The domains of observation variables are defined as follows:
- Dom(O^S)={High, Medium, Low}
- Dom(O^L)={On, Off}



POMDP model

Two possible actions (A):
- Blocking the heat vent- increases temperature by δ
- Unblocking the heat vent- decreases temperature by δ'

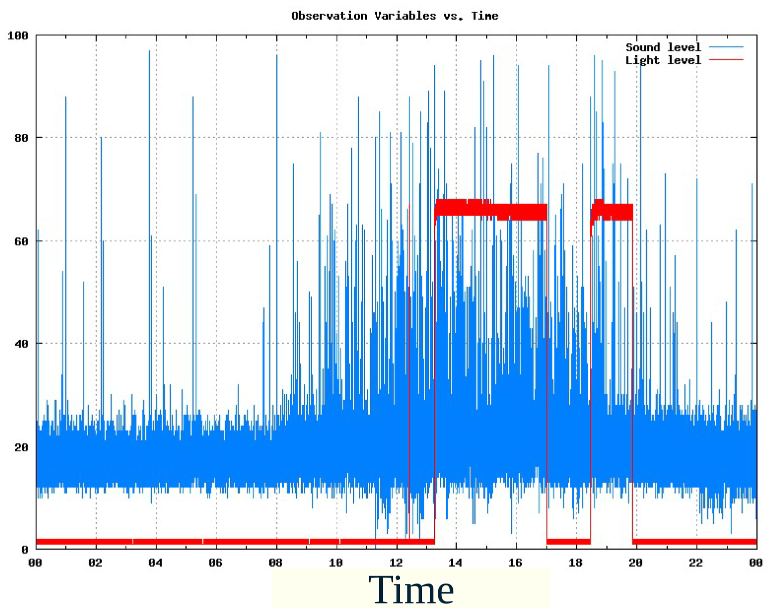
The reward function R is defined as a function both of the comfort of the occupants and of the energy consumed:

$$R = \begin{cases} |T_{preferred}-T|\cdot W_C & \text{when the room is active;} \\ |T_{setpoint}-T| \cdot W_E & \text{when the room is inactive} \end{cases}$$

Method

A. Activity Measurement Over a Week

- 24 WeatherDuck v2 sensors that measure temperature, humidity, light level, sound level, and air flow around them.
- Deployed in offices, labs and public areas in three floors of the Davis Center at the University of Waterloo.
- We poll each sensor every two seconds and collect data from the sensors into a central server weekly.
- Ground truth data is gathered manually by recording the activity inside one of the monitored rooms.



B. Determining Values of the Parameters (δ, δ', W_E, W_C, $T_{preferred}$ and $T_{setpoint}$)

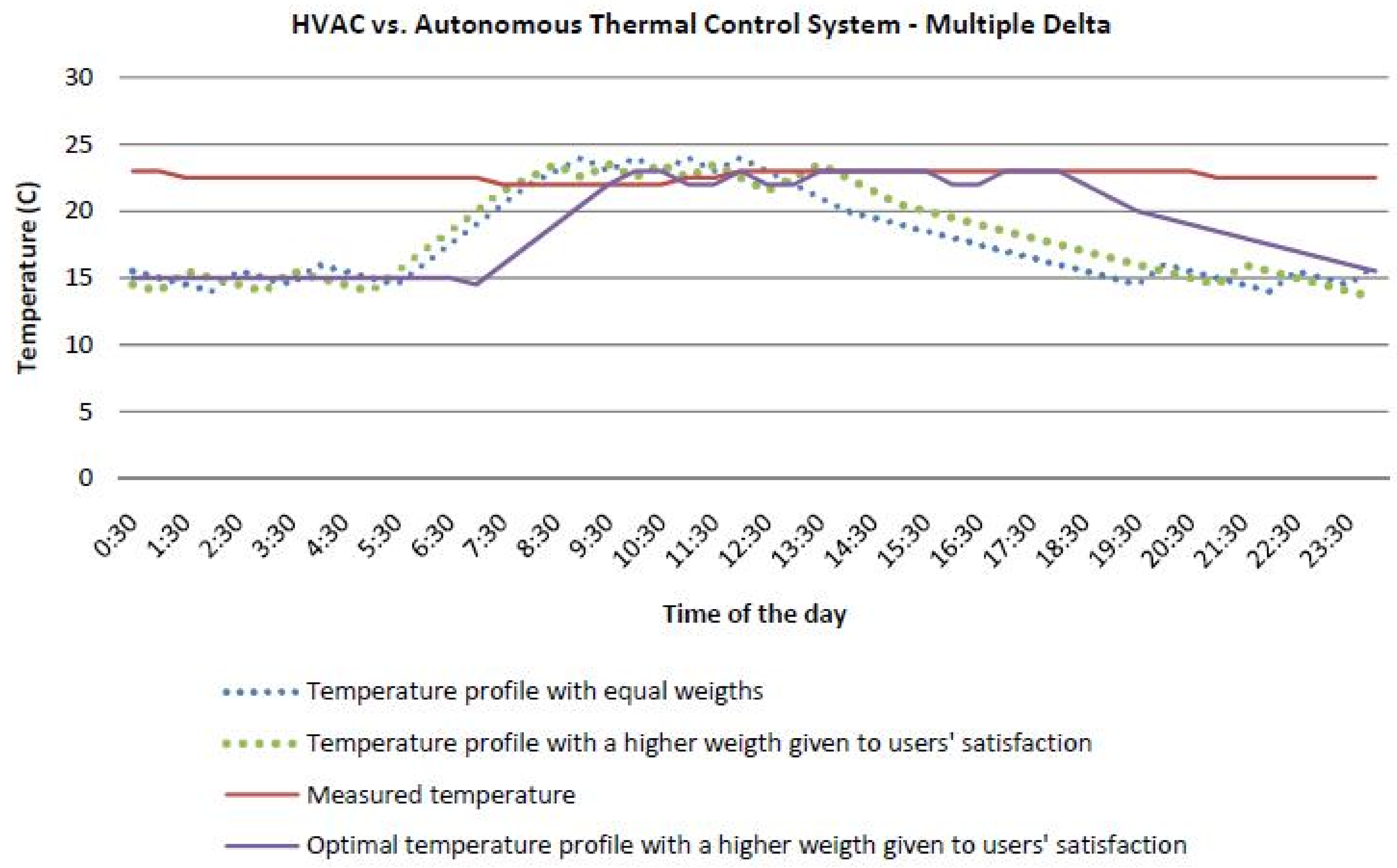
- We set values of δ and δ' to be +1 and -0.5 respectively for a half hour interval. These values are experimentally determined.
- We set the value of $T_{preferred}$ to be 23°C according to the ASHRAE standard 55. We also set the value of $T_{setpoint}$ to be 15°C.
- Different sets of values for the weight variables W_C and W_E are used in our experiments.

C. Solving the POMDP

- The factored POMDP with 27552 states is solved using the Perseus algorithm.
- We used the *Symbolic Perseus* package.

D. Results

- We traced an optimal policy by giving a set of observations as an input to the package. We compared temperature profiles for different weights of energy saving and thermal comfort with the optimal and measured temperature profiles.



Our experiment shows that Autonomous Thermal Control System approximately consumes 37.5% less energy than the HVAC system. Moreover, it can adjust itself according to the desired thermal comfort of each building occupant. Therefore, we believe that this system can enhance the performance of currently deployed HVAC systems.