Internal House Model for Predicting House Thermal Behavior

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Vision

The ultimate goal of DR thermostat development is to optimize utility cost and comfort in a very smart way based on users' thermal preference and their monthly budget limit. Unfortunately currently available commercial thermostats are passive in that they regulate indoor temperature mainly based on the setpoints users preset and the real-time energy use cannot affect their control strategies or setpoints directly. In order for a thermostat to be an autonomous control system, it is essential to predict house thermal behavior under any given condition.

This poster describes methodologies for identifying house thermal properties, and control strategies that can allow the DR thermostat to control the indoor temperature with adaptive setpoints. These include how to develop a reasonable internal house model for prediction and how to tune house parameters in the model as good defaults. This work underlies the house learning process.

In conclusion, the DR thermostat can resolve the following dilemma between thermostat users and thermostat developers.

> ***User : "I want a thermostat that can provide good out-of-box performance without bothering me with initial setup."***
> ***Developer : "I need information about the house where this thermostat will be installed."***

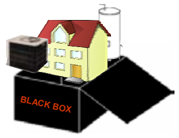
Methods

Internal House Model Development

The internal house model development starts from the basic assumption that a simplified house and HVAC equipment models can be used to provide reasonable prediction. The simplified model satisfies 1.the first order, 2. less than five unknown parameters, 3. use all of available information to increase prediction quality. The internal model has the following form

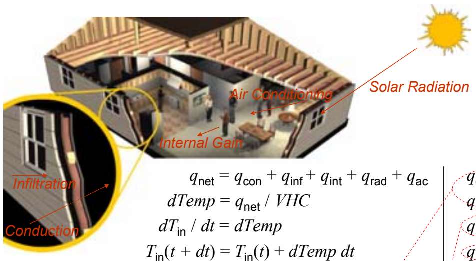
$$IndoorTemp(t + \Delta t) = f(indoorTemp(t), outdoorTemp(t), \ldots)$$

Measured input
Current indoor temp
Current outdoor temp
Current RH
Sunny/Cloudy



Predicted output
Future indoor temp

Known
Zip code, Current date, time, Available HVAC devices



$$
\begin{aligned}
q_{net} &= q_{con} + q_{inf} + q_{int} + q_{rad} + q_{ac} \\
dTemp &= q_{net} / VHC \\
dT_{in} / dt &= dTemp \\
T_{in}(t + dt) &= T_{in}(t) + dTemp\ dt \\
&= T_{in}(t) + q_{net}\ dt / VHC
\end{aligned}
$$

q_{con} = linear (T_{out} - T_{in})
q_{inf} = linear (T_{out} - T_{in})
q_{int} = constant
q_{rad} = linear(Global Radiation)
q_{ac} = constant

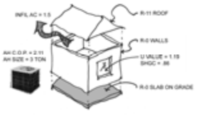
Simplified Equation

$$VHC \{Tin\ (t + dt) - Tin\ (t)\} / dt = \underline{\alpha\{Tout\ (t) - Tin(t)\}} + \underline{\beta} + \underline{\gamma(\text{global radiation})} + \underline{\delta\ (\text{AC status})}$$

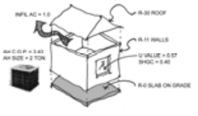
where α, β, γ, and δ are unknown parameters

Good Default Value Finding

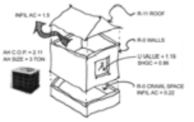
Typical California houses can be categorized into four types by age and insulation. Two houses in the left side were constructed before 1978 with 3 ton AC units and have a slab-on-grade foundation and a crawl space respectively. Another two houses in the right side were constructed after 1992 with 2 ton AC unitis. We will find 4 parameters (α, β, γ, and δ) by fitting the indoor temperature data to the simplified equation and combine them to produce good defaults. (Least Square Method)



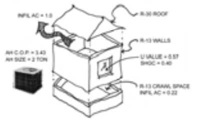
Pre **1978** Slab on Grade Model



Post **1992** Slab on Grade Model



Pre **1978** Crawl Space Model

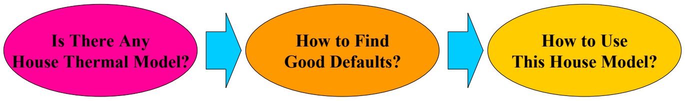


Post **1992** Crawl Space Model

Research Questions

Question 1. Is there any house thermal model that the DR thermostat can use to predict indoor temperature? Due to nonlinearity and complexity of real houses, currently available house thermal models have too many parameters we need to set before using them. Since the DR thermostat deals with randomly allocated houses without any given knowledge on them, a simplified model with small number of parameters is necessary.

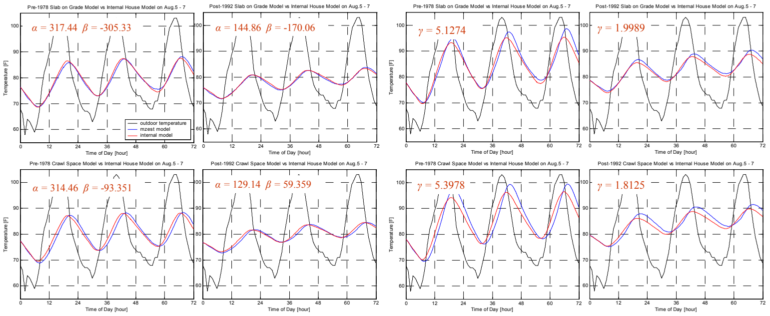
Question 2. Can we find good defaults with which out-of-box performance is reasonable for all California houses? After finding the simplified house model, we need to tune the parameters to cover the thermal behavior of typical Califonia houses.



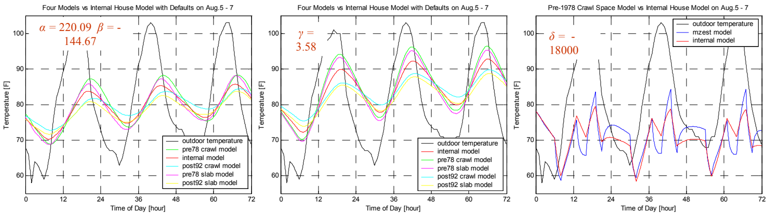
Is There Any House Thermal Model? → **How to Find Good Defaults?** → **How to Use This House Model?**

Findings

Internal House Model Validation : To guarantee that the simplified house model can provide reasonable prediction result, we compared the indoor temperature profiles from the MZEST (very close to real house thermal behavior) and the internal house model we developed. 3 parameters of the internal house model (α, β, and γ) are tuned respectively for 4 different houses. Under no solar radiation condition, the first two parameters (α and β) are calculated through Least Square Method. With pre-calculated α and β, the last parameter γ is calculated by considering solar radiation effect

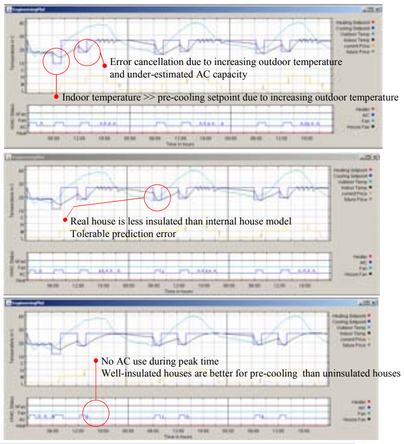


Good Defaults : To find optimal default values which fit well to most California houses, we tuned the values to minimize prediction error for all of 4 houses. As expected, these values are in the middle of above results. We should notice that we cannot obtain very accurate prediction with these defaults. However, it will guarantee "reasonable" prediction for any types of houses in California.



3-Day Simulation Result : The GoalSeeking layer in the DR thermostat control structure determines optimal setpoint based on the utility price, user preference, and house prediction. The simulation results in the right side show how well the prediction through the internal house model works. Two precooling periods in each day are shown and before these periods precooling setpoints and recovery time (total time from precooled temperature to normal setpoint) are predicted by the Supervisory Control layer.

Simulation with tuned parameters and pre 1978 Crawl Space Model (Top)
Simulation with good defaults and pre 1978 Crawl Space Model (Middle)
Simulation with good defaults and post 1992 Slab on Grade Model (Bottom)



Error cancellation due to increasing outdoor temperature and under-estimated AC capacity

Indoor temperature >> pre-cooling setpoint due to increasing outdoor temperature

Real house is less insulated than internal house model
Tolerable prediction error

No AC use during peak time
Well-insulated houses are better for pre-cooling than uninsulated houses

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