# Session 7 – Building Operation, Performance and Controls

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## Potential Heating Energy and Cost Savings of Dual Fuel Heat Pump Controls as a Residential Building Equipment Retrofit in the U.S.

# Learning Objectives

- Describe the Dual Fuel Heat Pump as a retrofit for residential buildings
- Describe how the Dual Fuel Heat Pump and its control work and how it affects energy and cost savings

# Acknowledgements


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- Thanks to Evan Rzeznik, Matt Evans from Newport Partners, and Anthony C Gehl from ORNL.

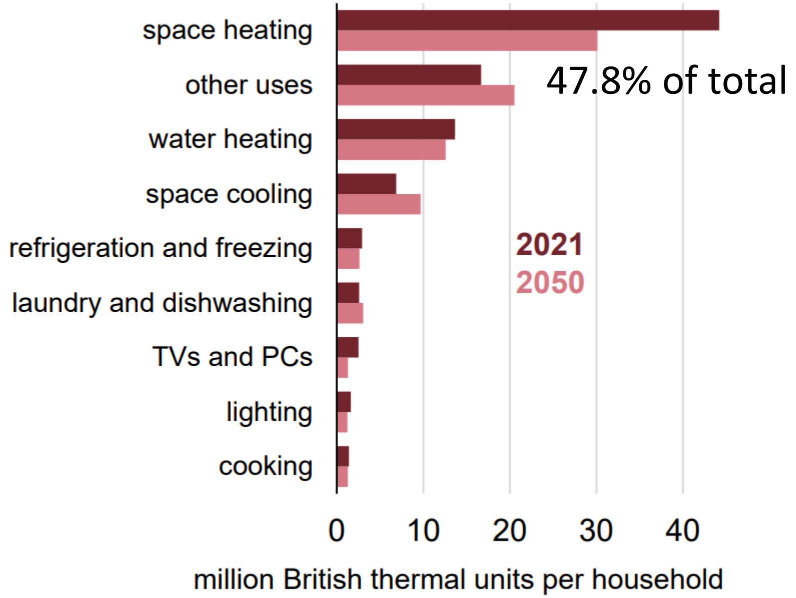
# Outline/Agenda

- Background
- Simulation Model Development
- Simulation Results: Winter Representative Week
- Simulation Results: Heating Season
- Conclusion

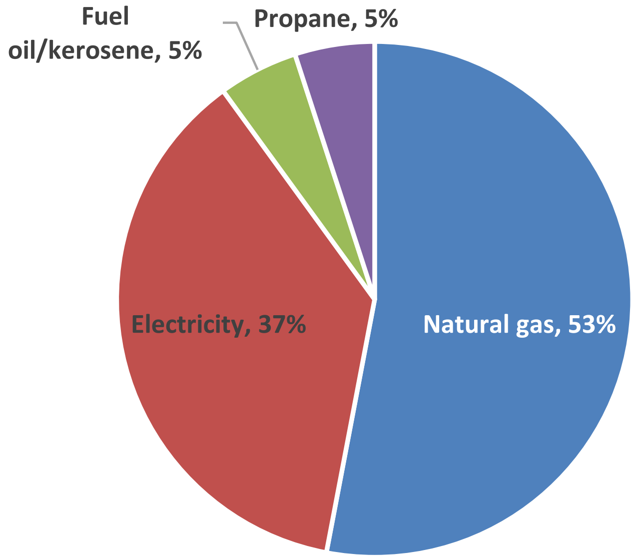
# Background

New administration has set a target to reduce **greenhouse gas emissions** by **50–52% by 2030** for a **carbon-neutral economy by 2050**.
In the **building sector**, the primary target of the **building decarbonization** has been **electrification** of building's **space heating source**, which is the major use of energy in both residential and commercial building.

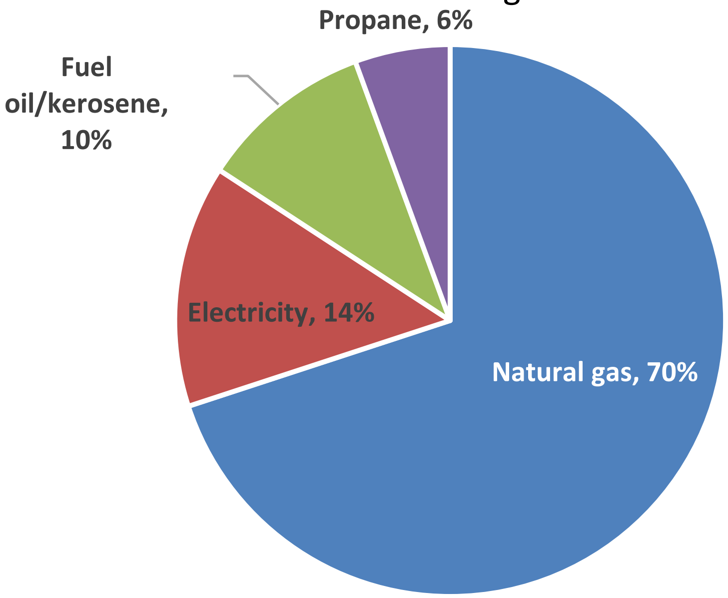
Energy intensity by end use in residential building*




Type of main heating fuel in the residential building sector**




Heating energy consumption by type of main heating fuel in the residential building sector**

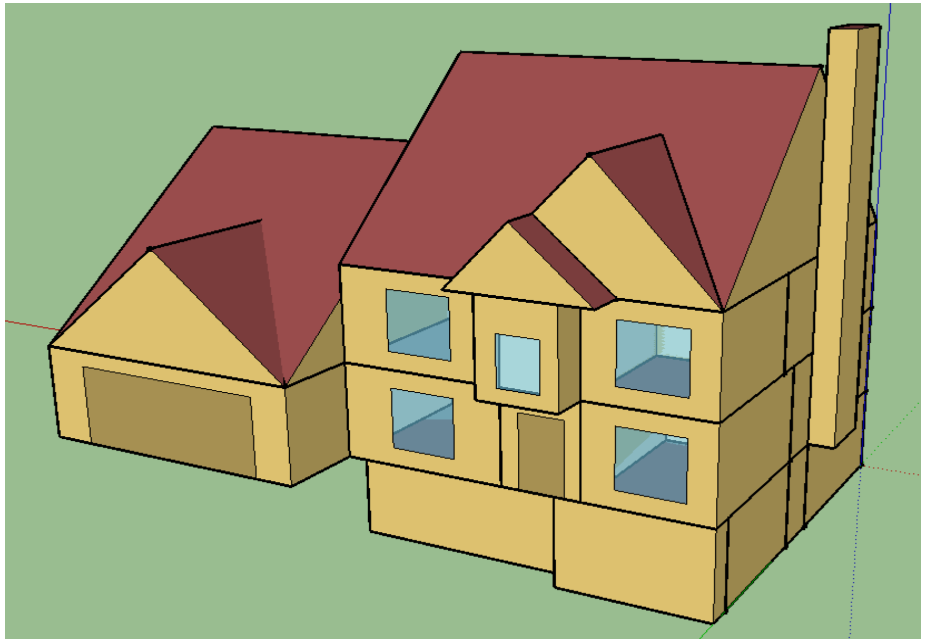


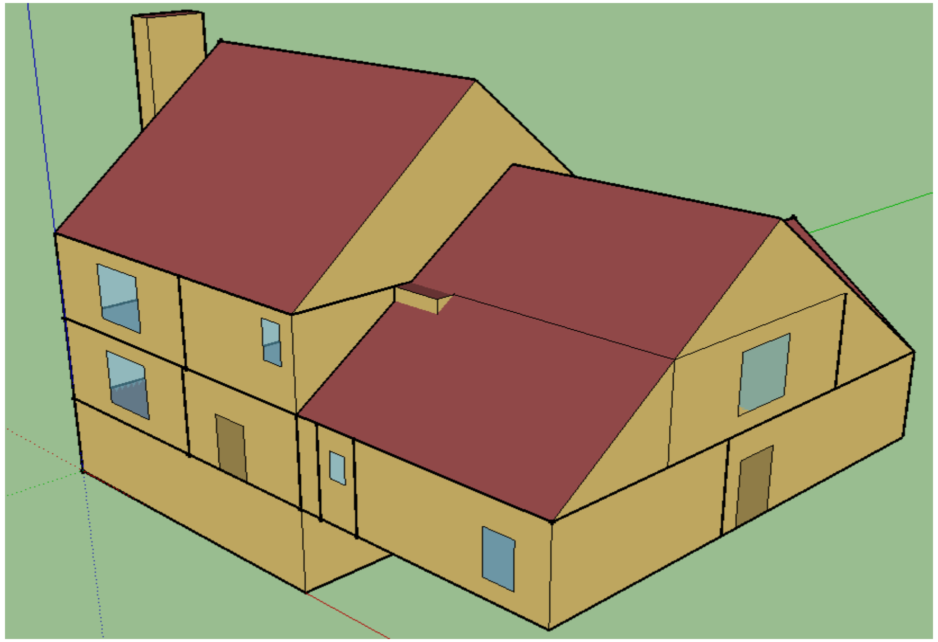

*EIA (US Energy Informaton Adminstration). 2018. 2018 Commercial Buildings Energy Consumption Survey (CBECS) data. Available at: https://www.eia.gov/consumption/commercial/EIA (US Energy Informaton Adminstration). 2022. Annual Energy Outlook 2022. Available at: https://www.eia.gov/outlooks/aeo/pdf/AEO2022_ChartLibrary_Buildings.pdf.

**EIA (US EIA (US Energy Informaton Adminstration). 2015. 2015 Residential Energy Consumption Survey (RECS) data. Available at: https://www.eia.gov/consumption/residential/data/2015/c&e/pdf/ce3.1.pdf.

# Simulation Model Development

## Test building





- Conditioned Area: 2,385 $ft^2$
- Building location: Albany, NY (Climate zone: 5A)
- Floors above grade: 2
- Basement: 1
- Bedrooms: 4

# Simulation Model Development

## Simulation program


**OpenStudio**
OpenStuio plug-in (SketchUp)
Geometry modeling

**EnergyPlus**
Detailed modeling
System modeling

**Python**
Control logic

# Simulation Model Development

## Simulation model inputs

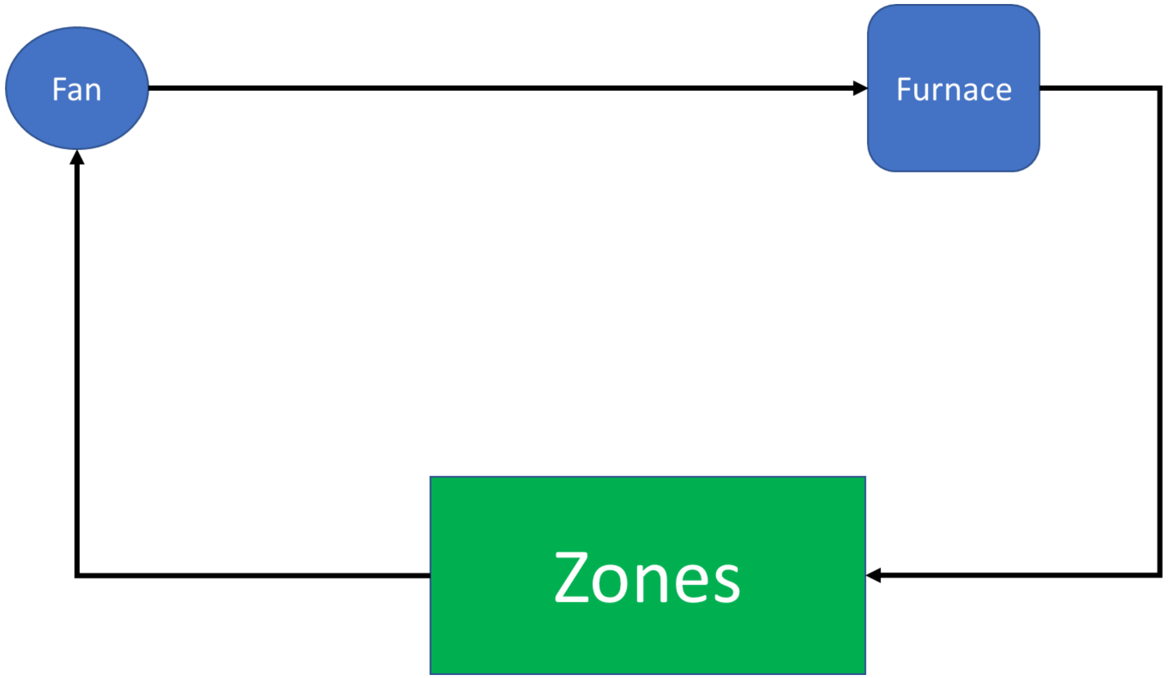
| | | Input value |
|---|---|---|
| U-value ($W/m^2 \cdot K$ ($Btu/h \cdot ft^2 \cdot F$)) | Exterior wall | 0.42 (0.074) |
| | Roof | 0.392 (0.069) |
| | Window | 2.61 (0.46) |
| Infiltration (ACH) | | 0.205 |
| People (#) | | 4 |
| Lighting ($W/m^2$ ($W/ft^2$)) | | 2.1 (0.195)* |
| Electric equipment (W) | | 124 |
| Heating setpoint (℃ (℉)) | | 20 (68) (4 AM to 10 PM) |
| Heating setback setpoint (℃ (℉)) | | 17.2 (63) (10 PM to 4 AM) |
| Hot water setpoint (℃ (℉)) | | 51.6 (125) |
| Capacity of gas furnace (kW (kBtuh)) | | 24.9 (85) |

All the values from the building summary report.

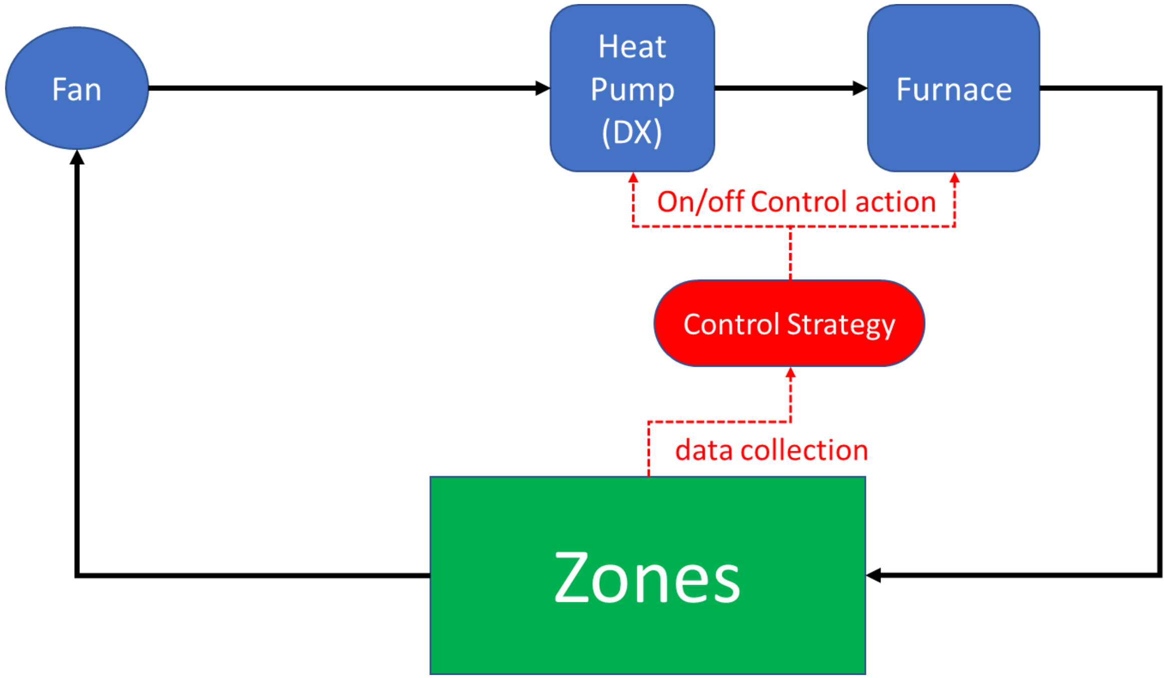
* IECC 2015 model. Available: https://www.energycodes.gov/prototype-building-models#Residential

# Simulation Model Development

Heating system diagram

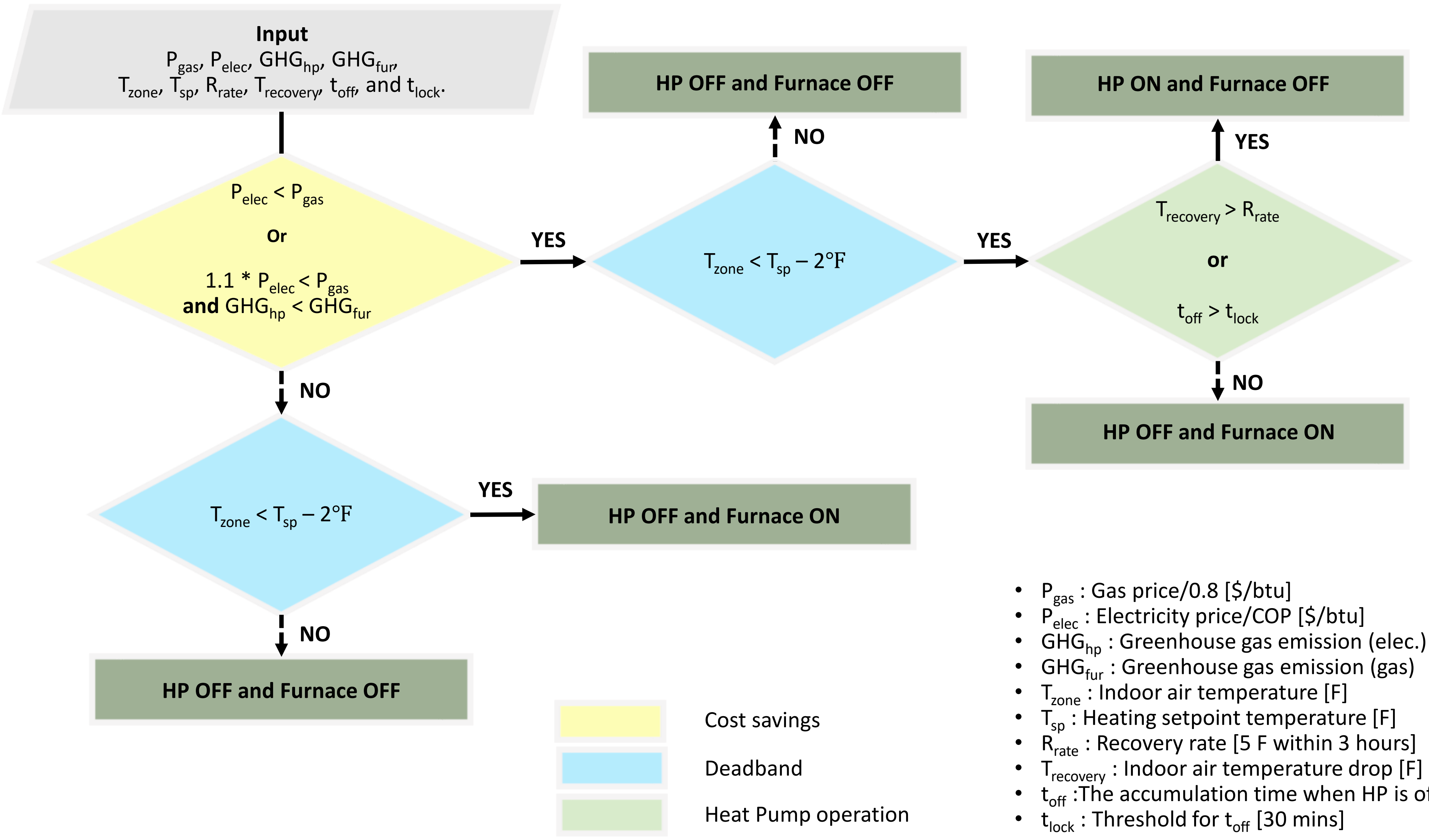



Base model




Dual Fuel Heat Pump

# Simulation Model Development

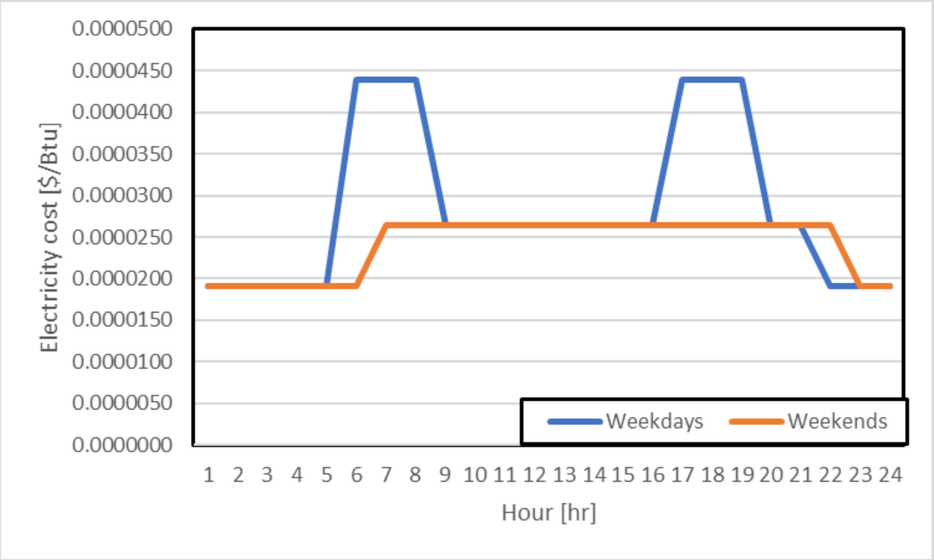



- $P_{gas}$ : Gas price/0.8 [$/btu]
- $P_{elec}$ : Electricity price/COP [$/btu]
- $GHG_{hp}$ : Greenhouse gas emission (elec.)
- $GHG_{fur}$ : Greenhouse gas emission (gas)
- $T_{zone}$ : Indoor air temperature [F]
- $T_{sp}$ : Heating setpoint temperature [F]
- $R_{rate}$ : Recovery rate [5 F within 3 hours]
- $T_{recovery}$ : Indoor air temperature drop [F]
- $t_{off}$ :The accumulation time when HP is off [min.]
- $t_{lock}$ : Threshold for $t_{off}$ [30 mins]

# Simulation Model Development

## Cost of utilities

### Electricity cost




**On-Peak**

**Mid-Peak**

**Off-Peak**

### Gas cost

| (2025 dollars per million Btu) | |
|---|---|
| Reference Case | 10.29 |

| 0.01029 $/kBtu |
|---|

* Source: U.S. EIA 2021 Annual Energy Outlook, Residential Natural Gas Price for 2026, Reference Cas

<table>
<tr><th></th><th>1:00 AM</th><th>2:00 AM</th><th>3:00 AM</th><th>4:00 AM</th><th>5:00 AM</th><th>6:00 AM</th><th>7:00 AM</th><th>8:00 AM</th><th>9:00 AM</th><th>10:00 AM</th><th>11:00 AM</th><th>12:00 PM</th><th>1:00 PM</th><th>2:00 PM</th><th>3:00 PM</th><th>4:00 PM</th><th>5:00 PM</th><th>6:00 PM</th><th>7:00 PM</th><th>8:00 PM</th><th>9:00 PM</th><th>10:00 PM</th><th>11:00 PM</th><th>12:00 AM</th></tr>
<tr><td>Weekdays</td><td colspan="5">$0.0191/kBtu</td><td colspan="3">$0.0440/kBtu</td><td colspan="8">$0.0264/kBtu</td><td colspan="3">$0.0440/kBtu</td><td colspan="2">$0.0264/kBtu</td><td colspan="3">$0.0191/kBtu</td></tr>
<tr><td>Weekends</td><td colspan="6">$0.0191/kBtu</td><td colspan="16">$0.0264/kBtu</td><td colspan="2">$0.0191/kBtu</td></tr>
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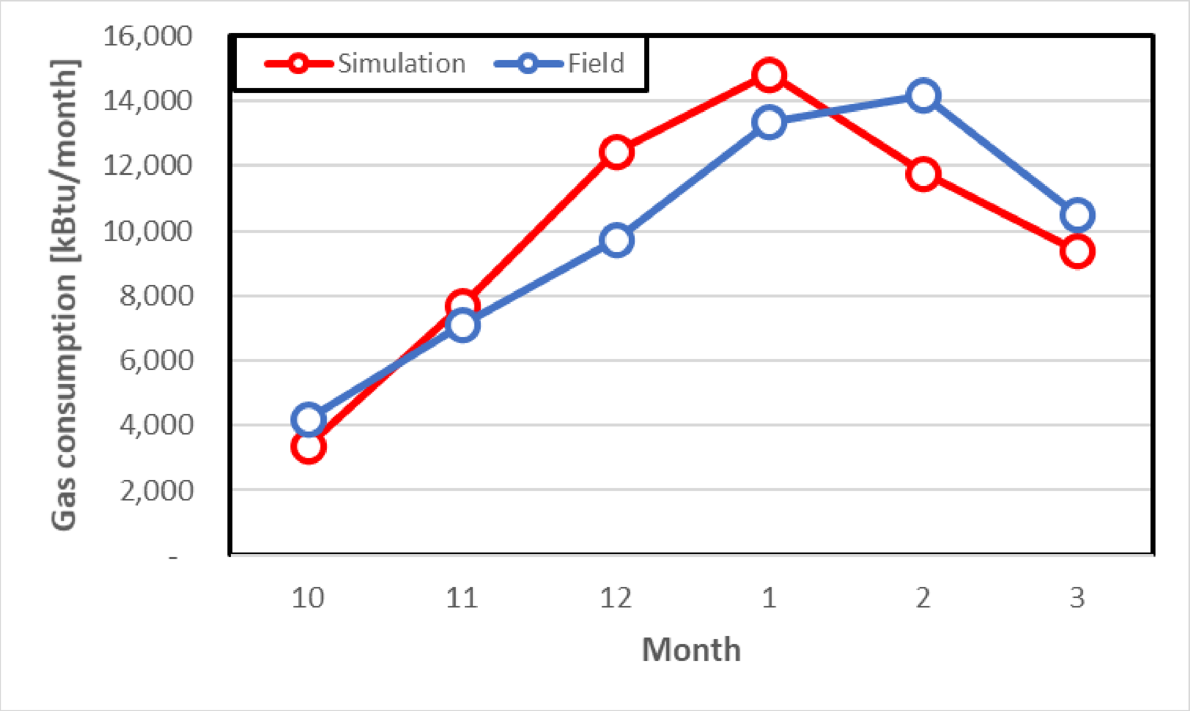
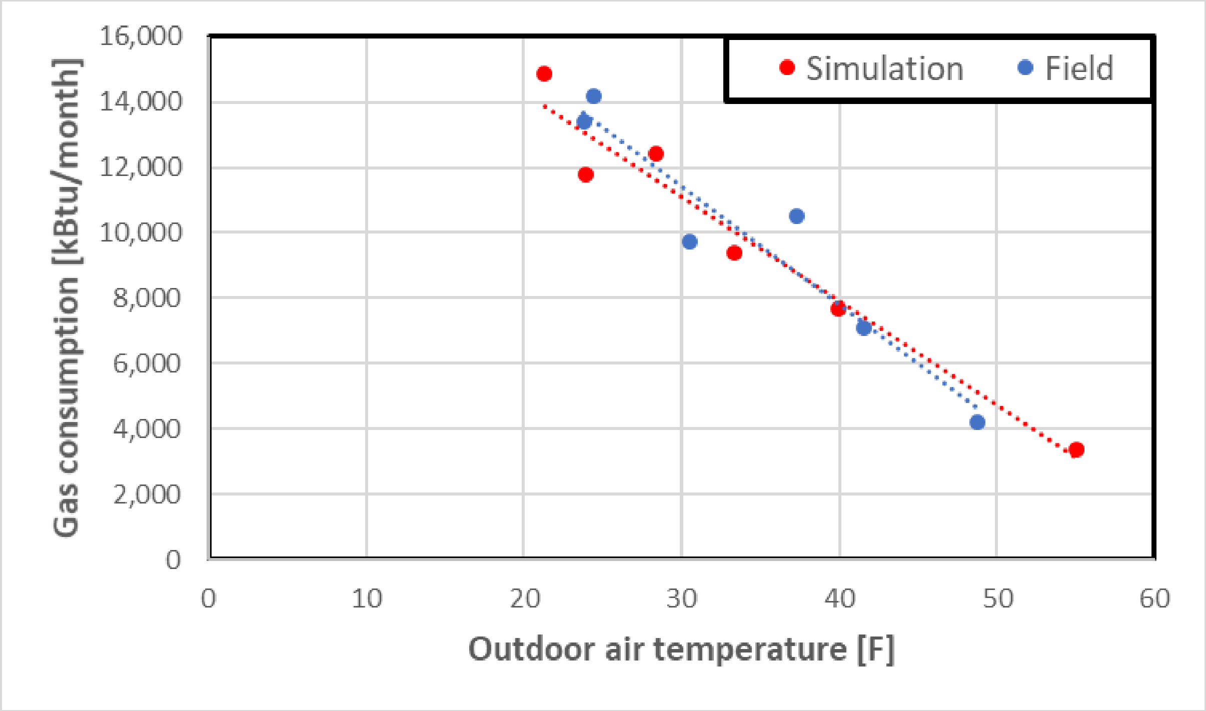
# Simulation Model Development

Monthly energy consumption comparison



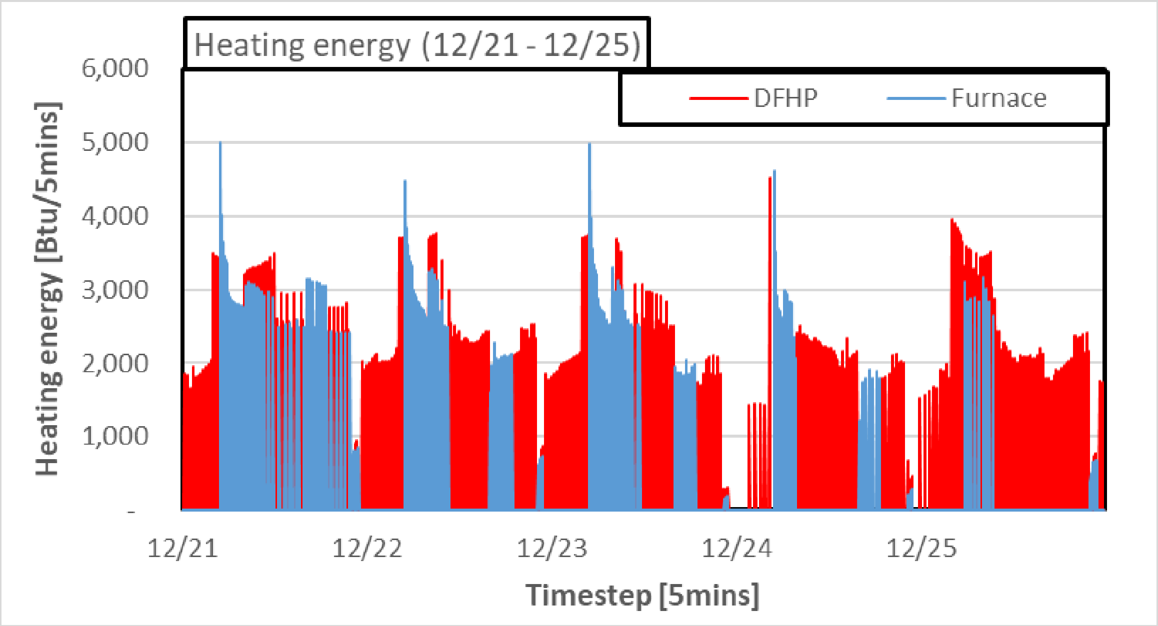

Monthly gas consumption comparison



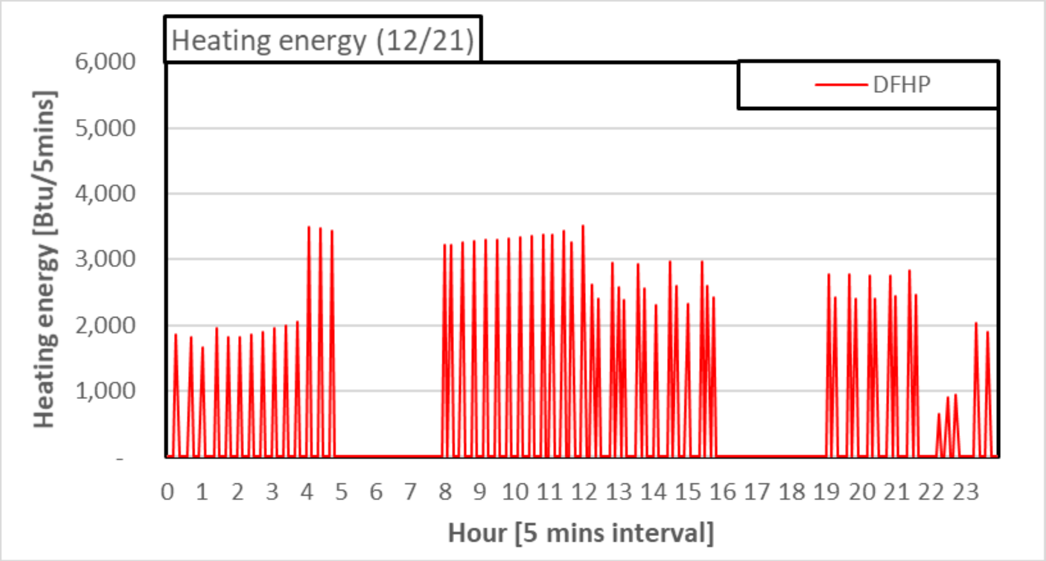

Monthly gas consumption vs. monthly average outdoor air temperature

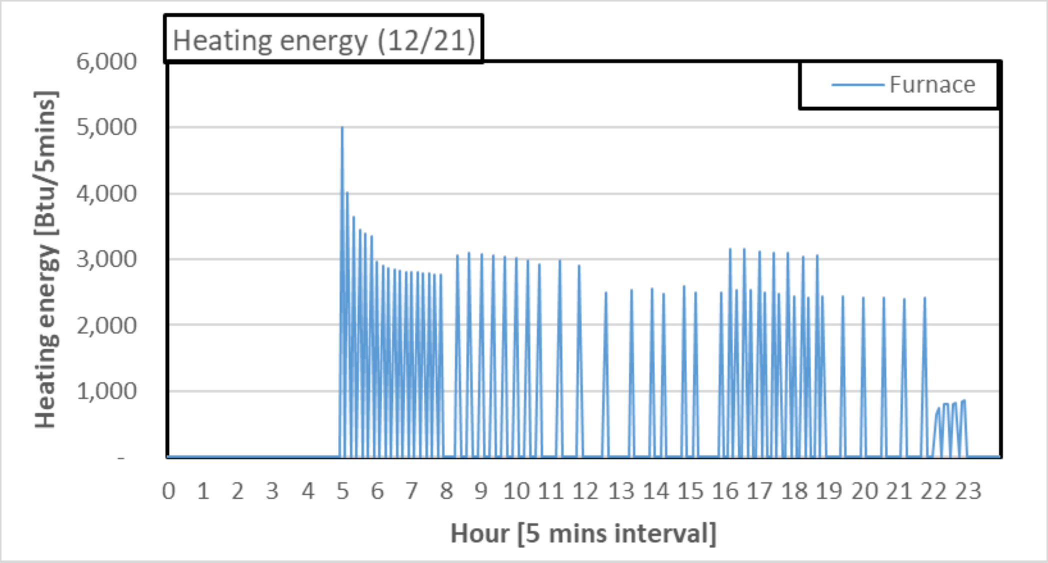
# Simulation Results: Winter Representative Week

## Dual Fuel Heat Pump system operation



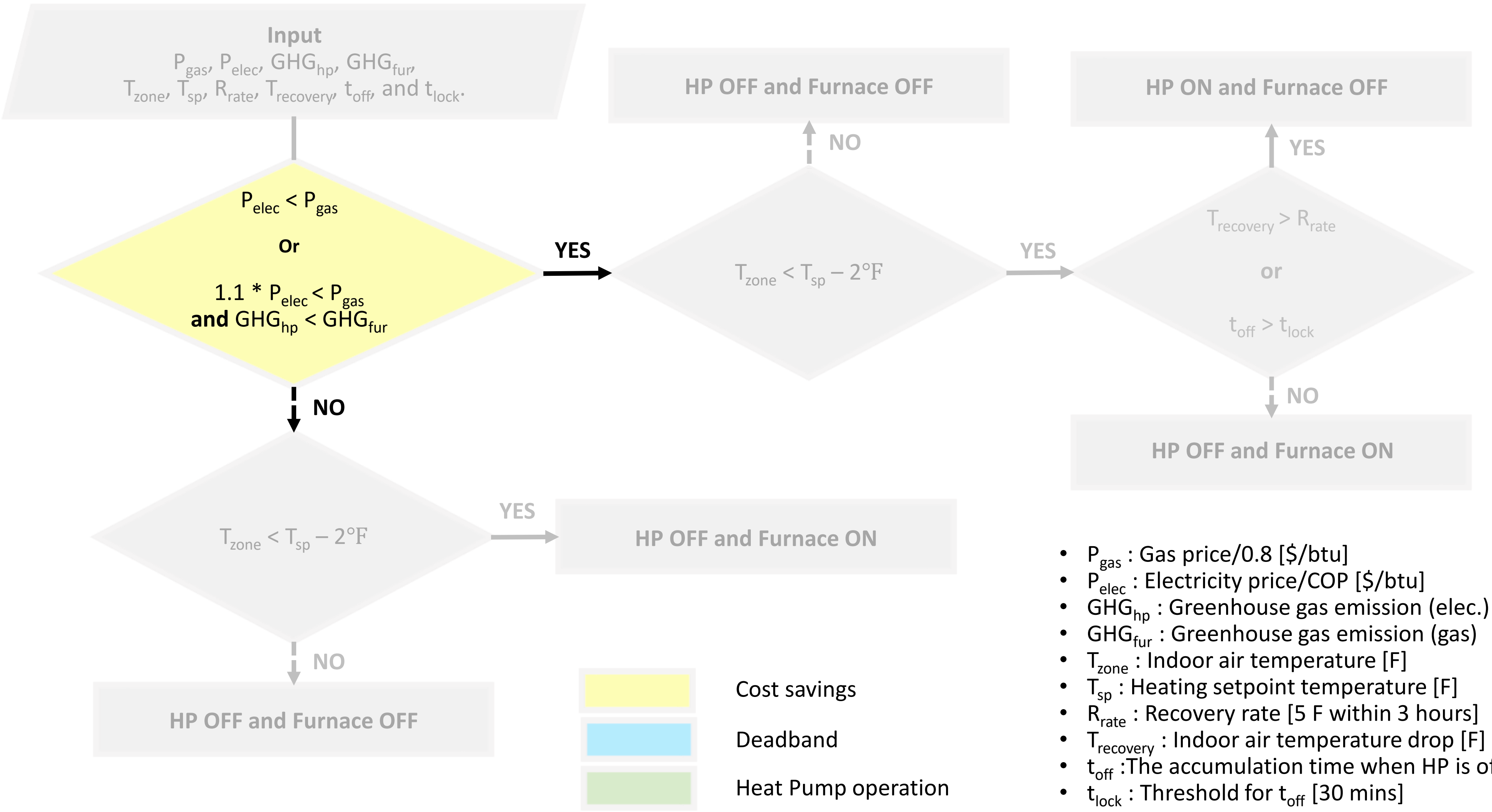

Heating energy consumption pattern
in winter representative week



# Simulation Results: Winter Representative Week

## Control algorithm – Cost savings part

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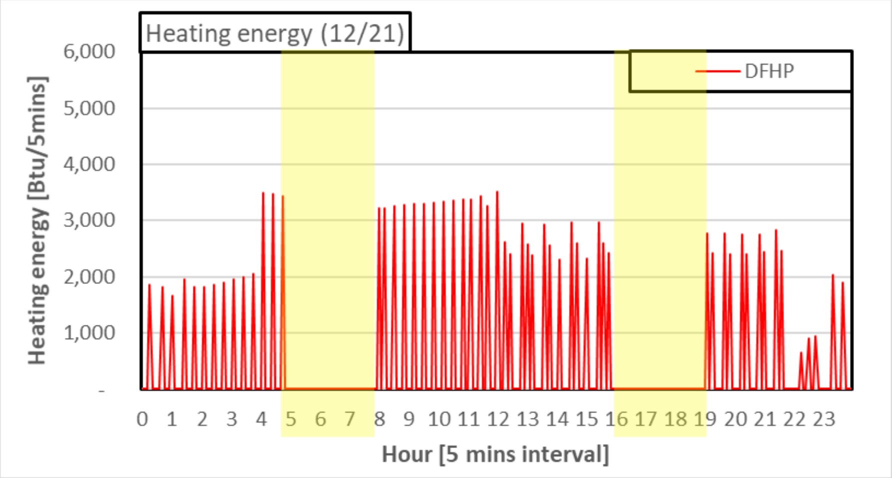
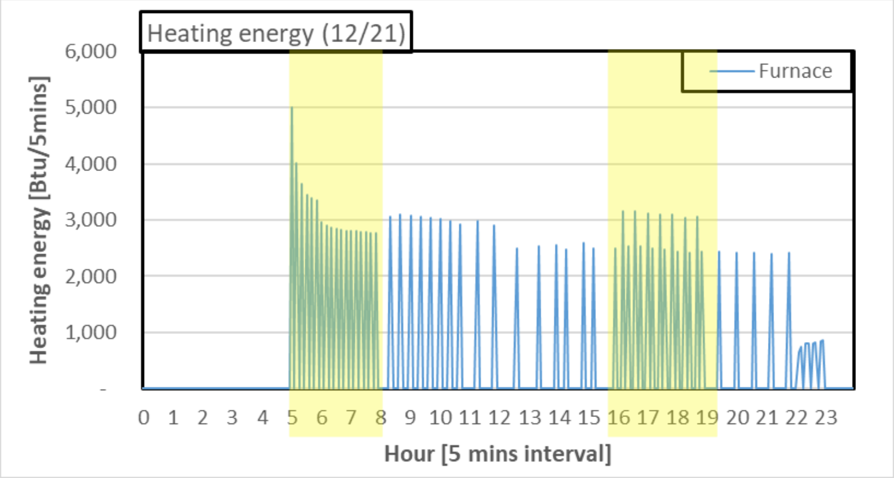
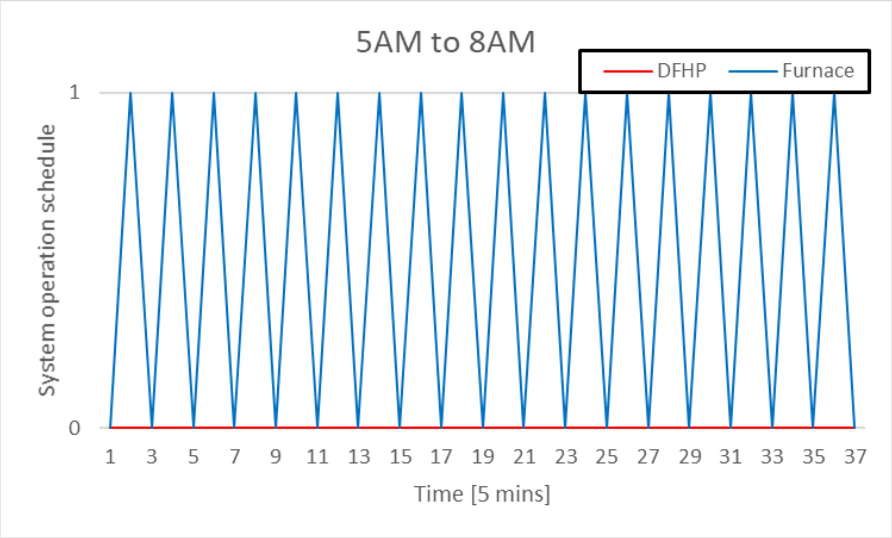
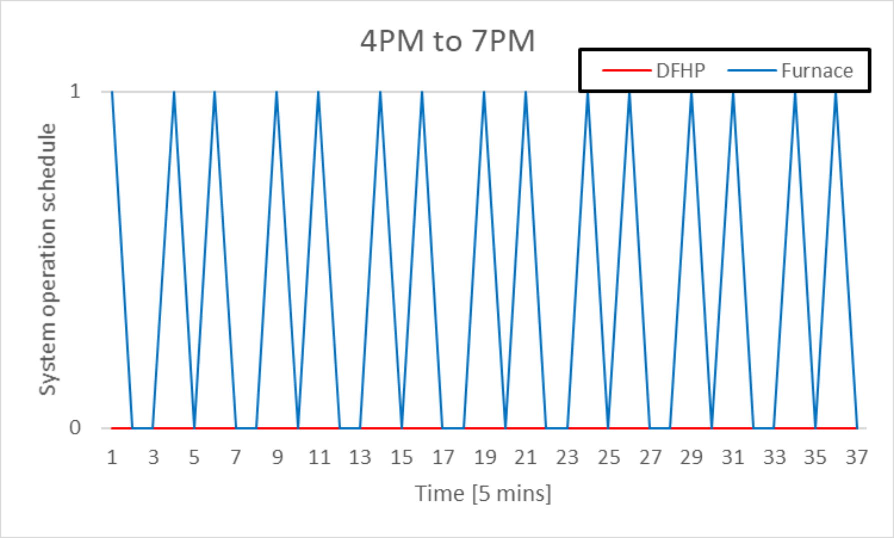
# Simulation Results: Winter Representative Week

## Heating system operation – Cost savings



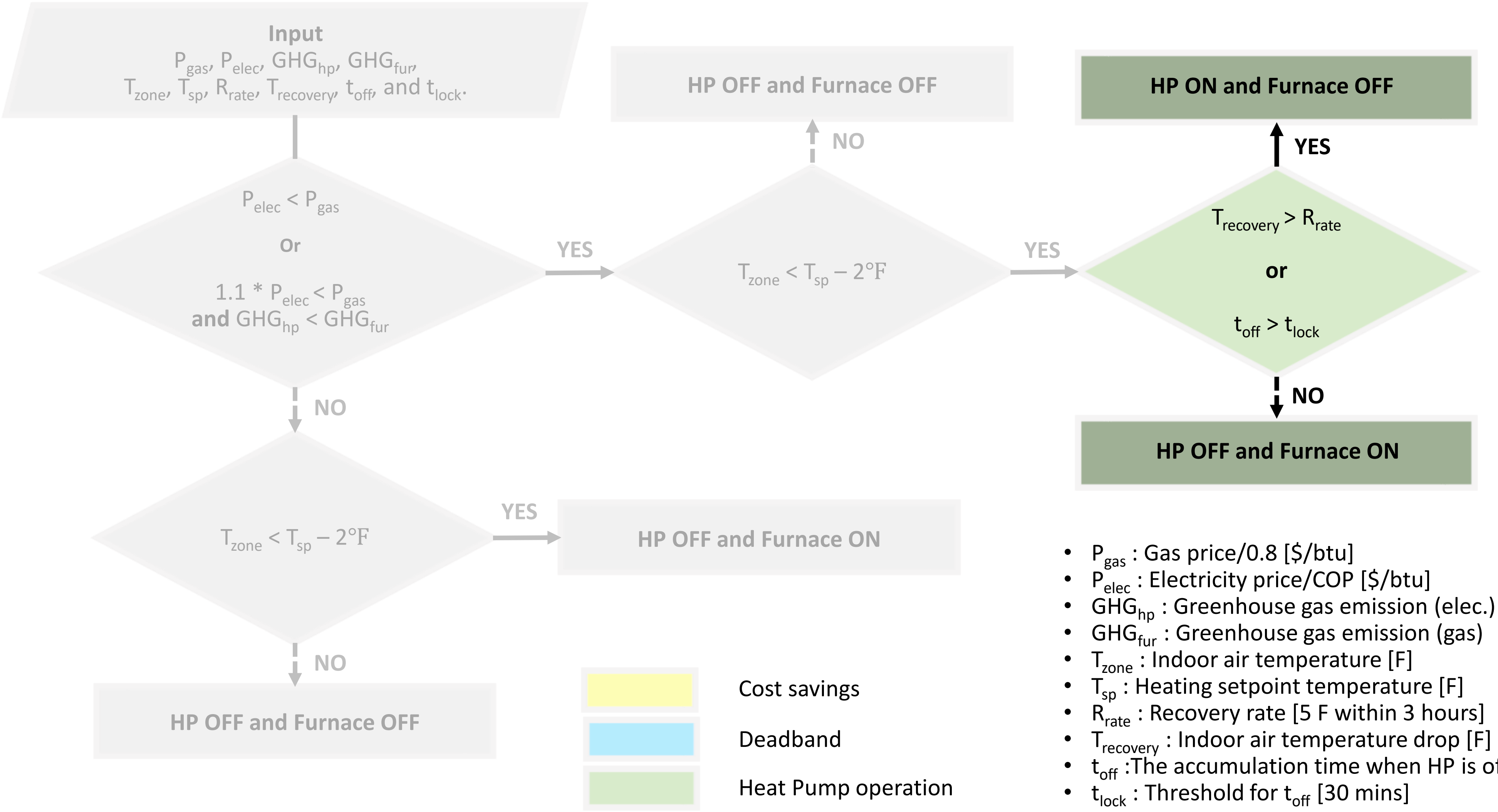



# Simulation Results: Winter Representative Week

## Control algorithm – Heat pump operation part

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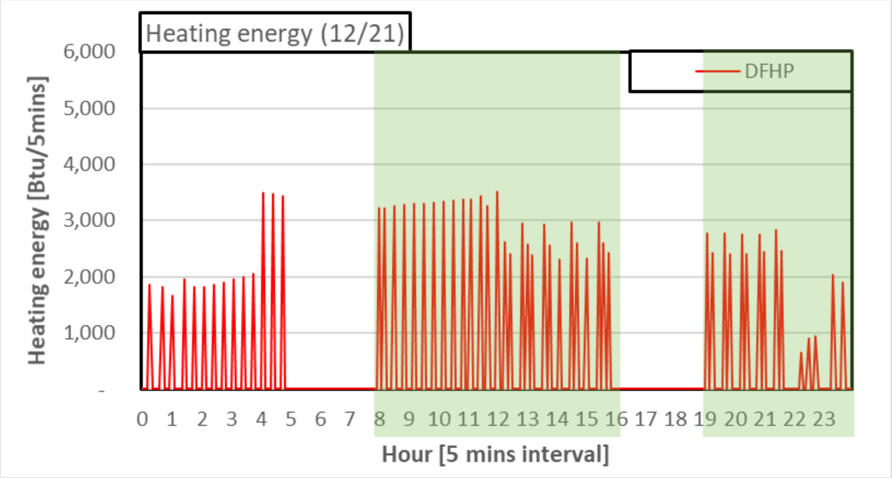
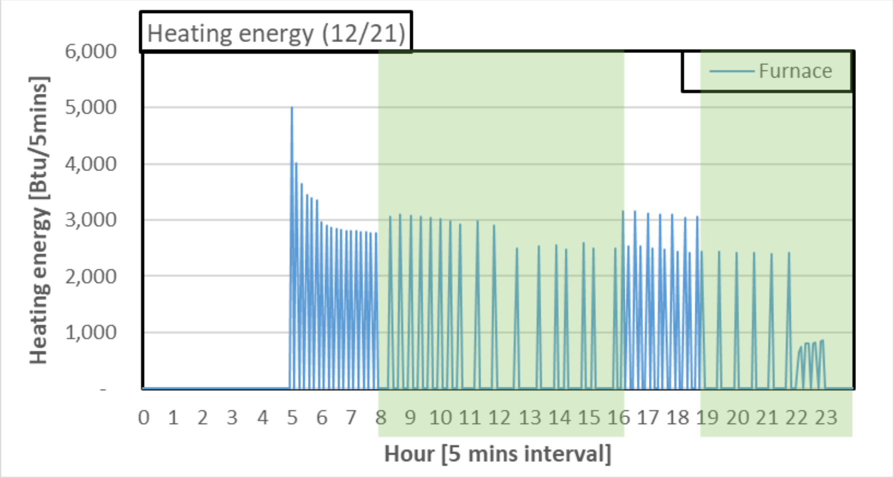
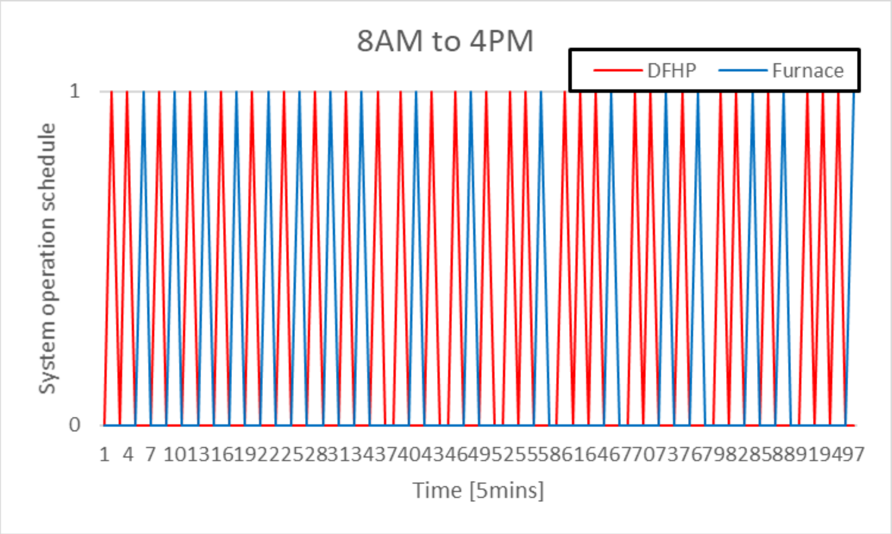
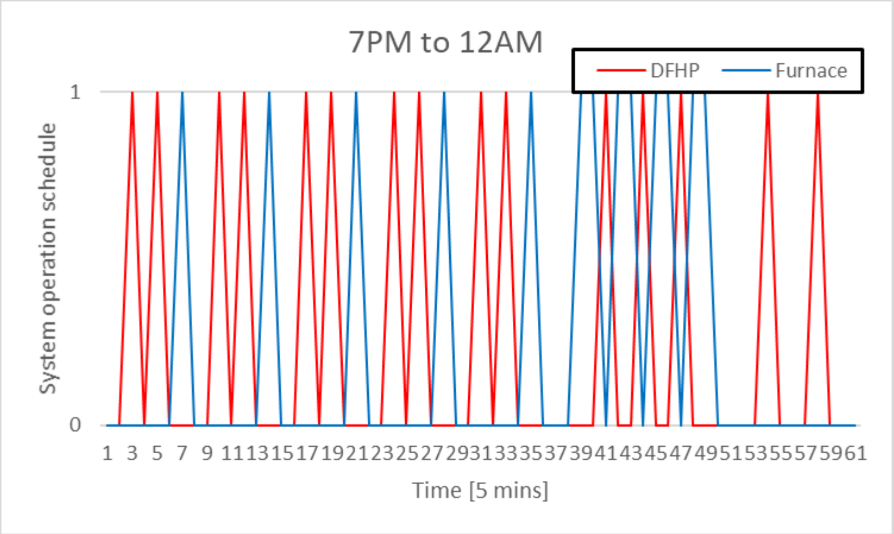
# Simulation Results: Winter Representative Week

## Heating system operation – Heat pump operation



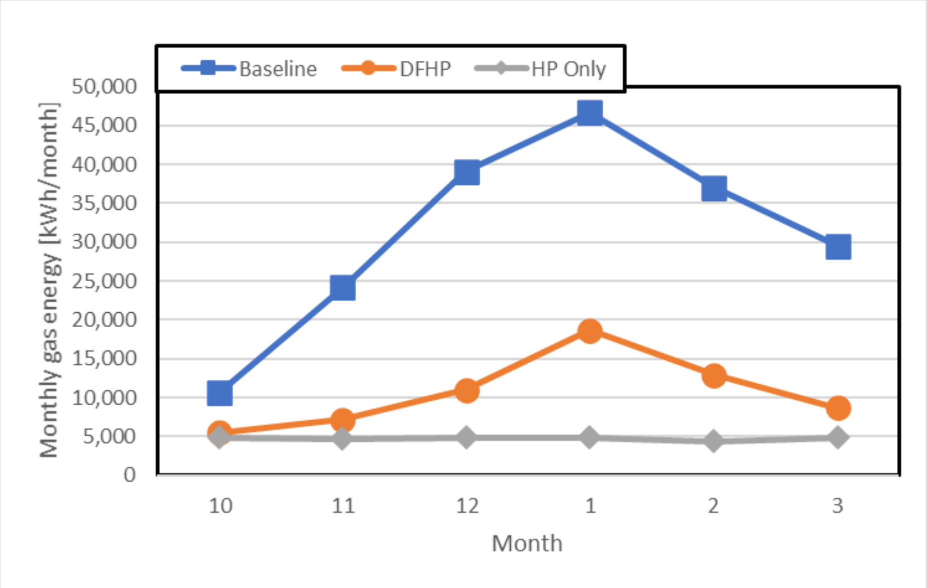



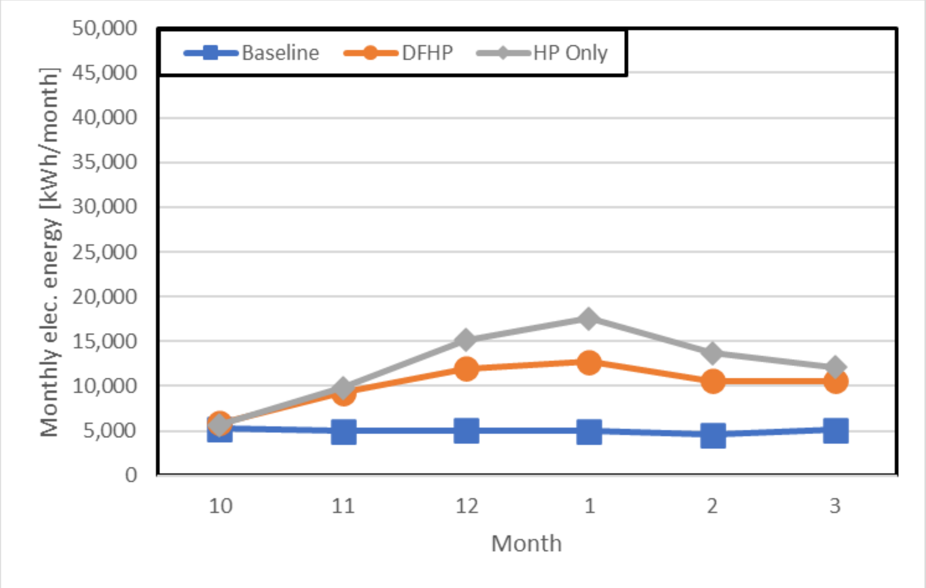



# Simulation Results: Heating Season

## Monthly site energy saving analysis



Comparison of monthly site energy consumption (Gas)

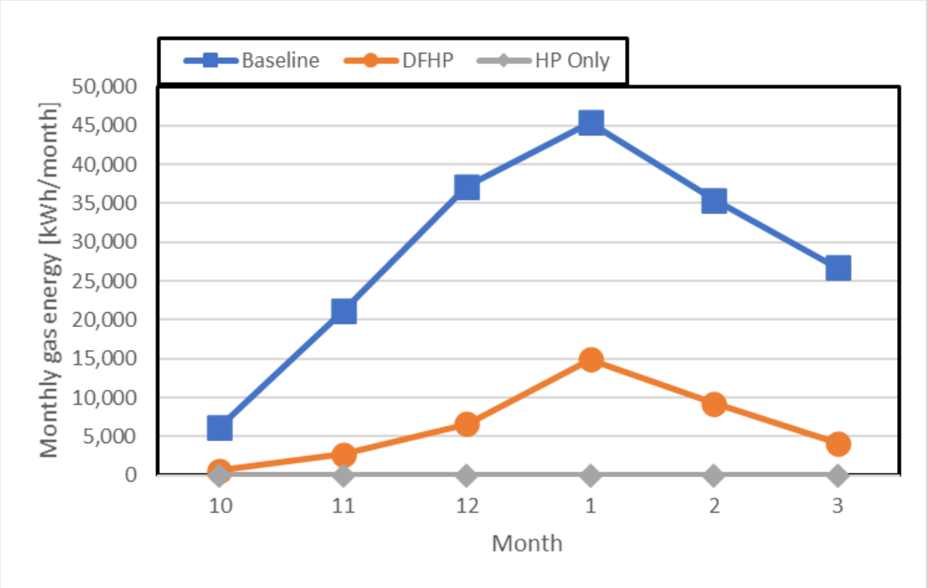


Comparison of monthly site energy consumption (Electricity)

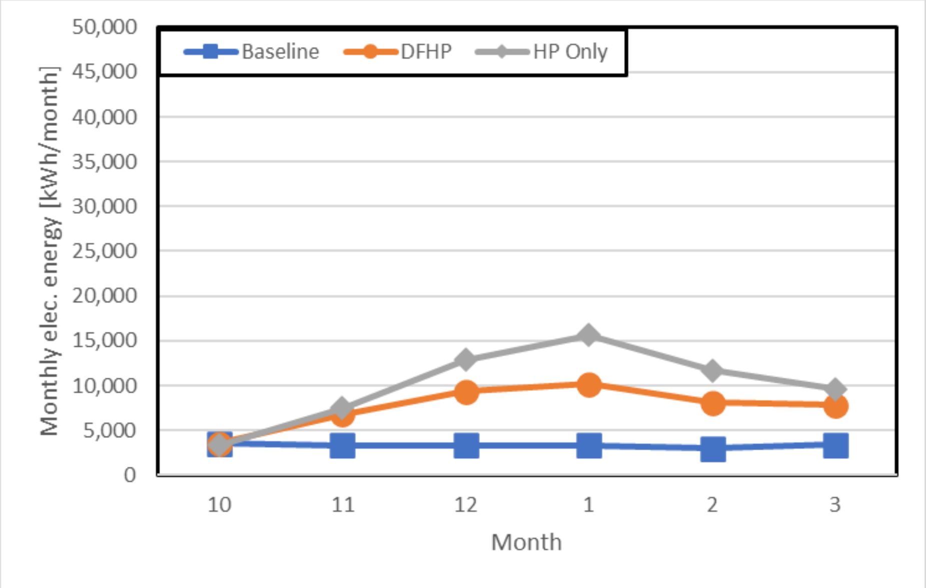
| | Base case | Dual Fuel Heat Pump | Heat Pump |
|---|---|---|---|
| Gas (kWh/year) | 186,983 | 64,006 | 28,543 |
| Electricity (kWh/year) | 30,041 | 60,989 | 74,022 |
| Total (kWh/year) | 217,024 | 124,995 | 102,565 |
| Energy savings (%) | - | 42.4 % | 52.7 % |

# Simulation Results: Heating Season

## Monthly heating energy saving analysis




Comparison of monthly heating energy consumption (Gas)

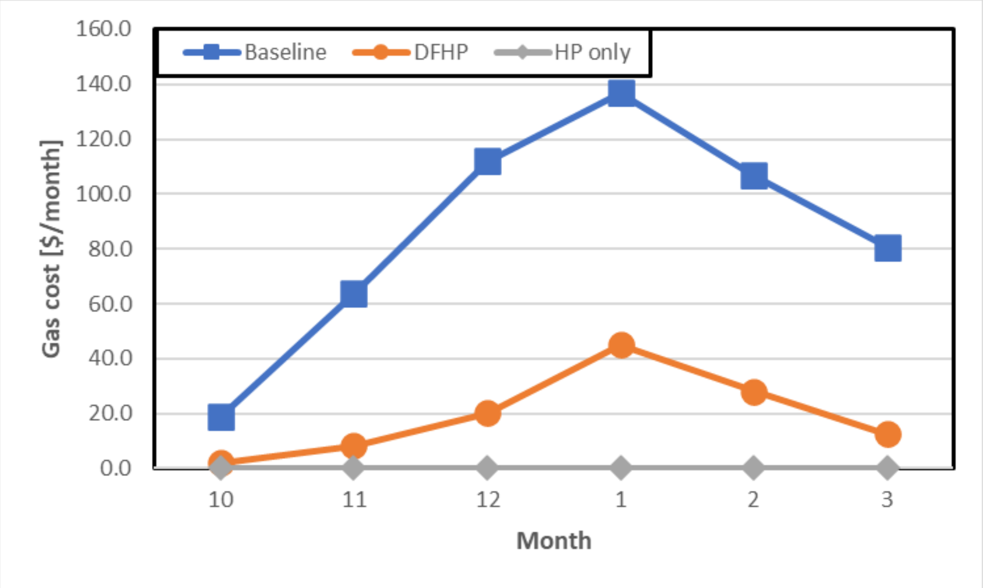



Comparison of monthly heating energy consumption (Electricity)

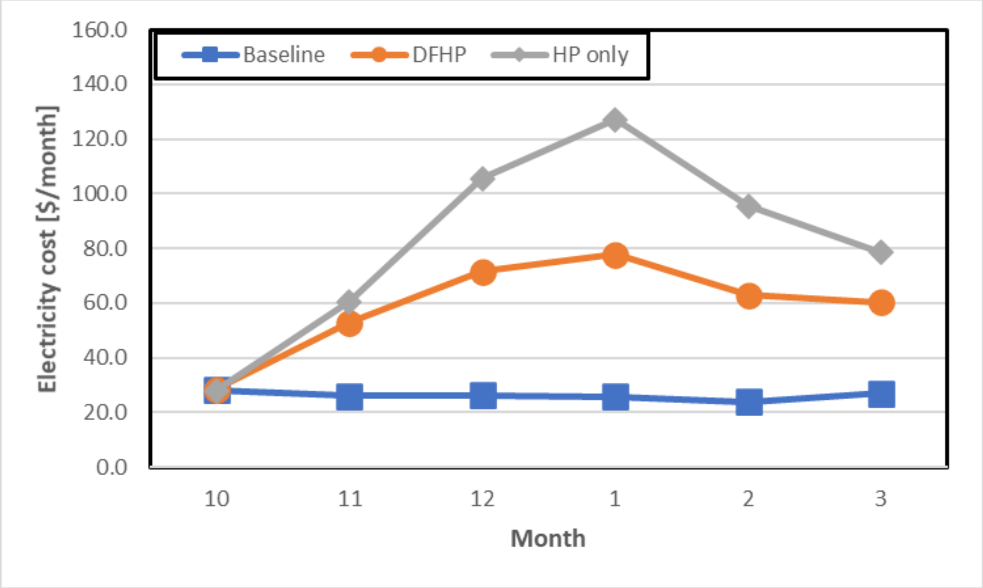
| | **Base case** | **Dual Fuel Heat Pump** | **Heat Pump** |
|---|---|---|---|
| Gas (kWh/year) | 172,056 | 38,511 | 0 |
| Electricity (kWh/year) | 19,965 | 45,665 | 60,566 |
| Total (kWh/year) | 192,021 | 84,177 | 60,566 |
| Energy savings (%) | - | 56.2 % | 68.5% |

# Simulation Results: Heating Season

## Monthly operational cost savings analysis




Gas operational cost in each case




Electricity operational cost in each case

| | Base case | Dual Fuel Heat Pump | Heat Pump |
|---|---|---|---|
| Gas ($/year) | 518.89 | 116.14 | 0 |
| Electricity ($/year) | 157.10 | 354.08 | 494.93 |
| Total ($/year) | 675.99 | 470.22 | 494.93 |
| Cost savings (%) | - | 30.44 % | 26.78% |

# Conclusions

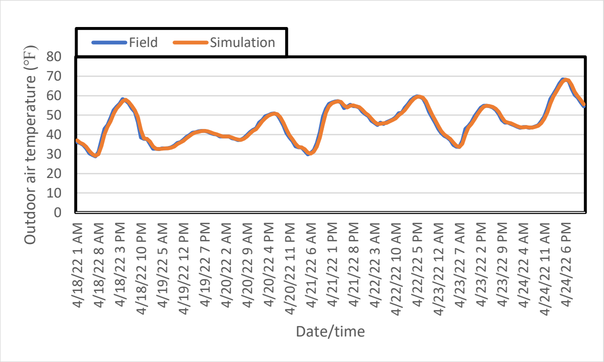
- This paper proposed the DFHP system and its control as a retrofit for residential buildings in cold climate zones.
- For the DFHP control, we implemented Python-based control logic for both energy and cost savings to the EnergyPlus simulation model.
- Even if the HP-only case consumed less gas and electric energy for heating, the HP only case consumed electricity even when the electricity rate is high.
- For this reason, the DFHP case is the optimal case that can significantly reduce both cost and energy consumption.

# Remaining Work

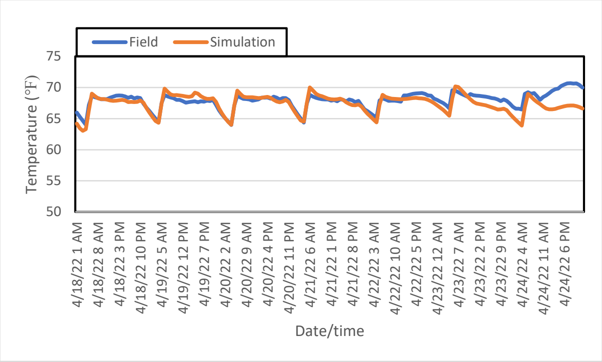
- Installed the temperature/humidity sensors, and energy meter
- Gathered gas furnace scenario data
- Installed the solar radiation sensor on site – April 2022
- Calibrated baseline simulation model

- Will install the HP to the test building for DFHP scenario test in the coming winter
- Will calibrate DFHP model with field data
- May revise the DFHP control logic to maximize energy and cost savings.

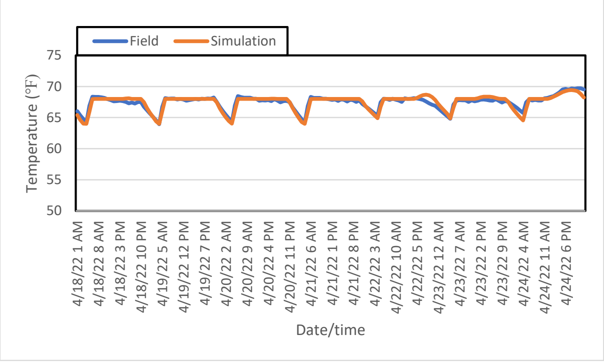
# Calibration results



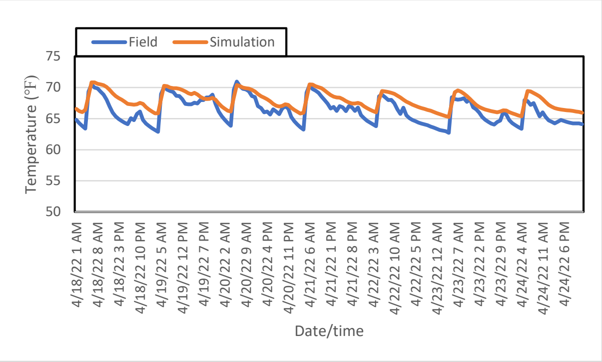

Outdoor air temperature



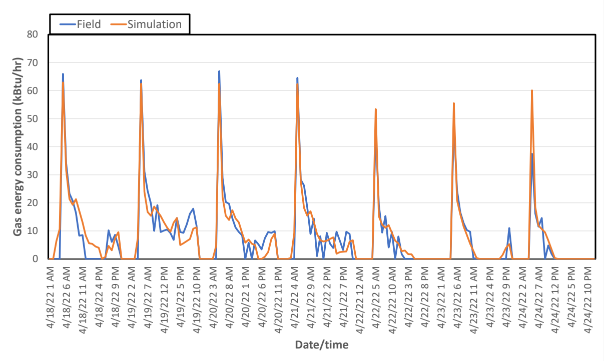

Indoor air temperature (master bedroom)



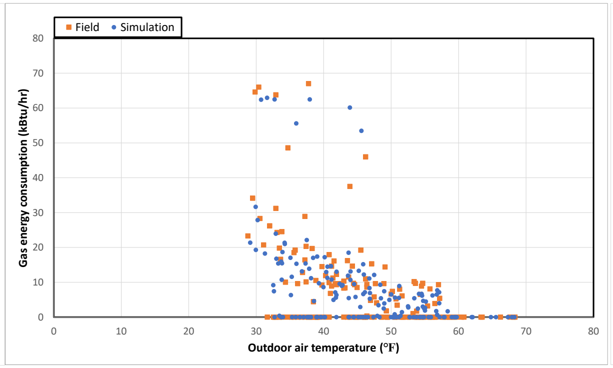

Indoor air temperature (living room)



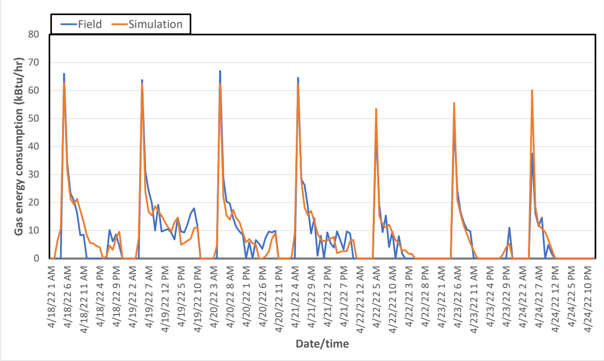

Indoor air temperature (Basement)



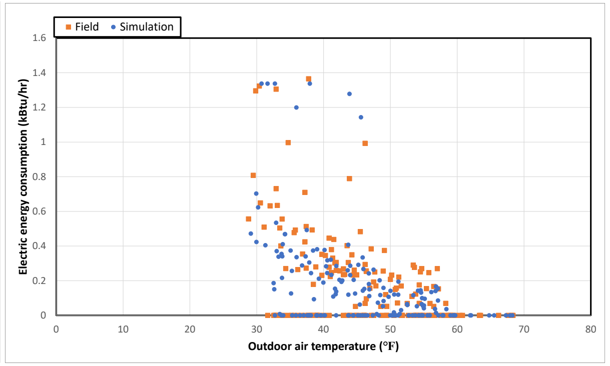

Gas energy consumption




Gas energy vs. Outdoor air temperature




Electric energy consumption




Elec. energy vs. Outdoor air temperature

# Bibliography

Yeobeom Yoom, Yanfei Li, Piljae Im, and James Lyons. 2022. Potential Heating Energy and Cost Savings of Dual Fuel Heat Pump Controls as a Residential Building Equipment Retrofit in the U.S. Presented at the 2022 Building Performance Analysis Conference and SimBuild, Chicago, IL, September 14-16.

# QUESTIONS?

Thank you for your attention!

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