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Seminar 13 – Yes, it is Your Fault How Faults Affect Your System's Performance and How to Model the Faults' Effects in Advance

Effect of Heat Pump Commissioning Faults on Annual Energy Use

Learning Objectives

- Objective 1: Describe the effect of heat pump installation faults on the annual energy use in a residential house in different U.S. climates
- Objective 2: See gray box modeling methods for simulating several important faults on a unitary air-conditioner
- Objective 3: Understand the impact of air-side economizer faults on whole-building energy performance
- Objective 4: See how to model the impacts of common unitary equipment faults on capacity, efficiency and other key performance parameters

Acknowledgements

- Co-authors of the study:

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  CDH Energy Corporation, Cazenova, NY

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- Study performed within Annex 36, Quality Installation/Quality Maintenance Sensitivity Studies, IEA Heat Pump Program

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  Oak Ridge National Laboratory, Oak Ridge, TN

Outline

- **Introduction & scope of the study**
- **Modeling methodology**
- **Effect faults on energy consumption**
  - Single faults
  - Dual faults
- **Conclusions**

How to reduce energy consumption by ACs and HPs?

- **Reduce the cooling and heating load**
  - High-performance buildings

- **Improve design energy efficiency of ACs and HPs**
  - 1992; minimum SEER 10
  - 2006; minimum SEER 13
  - 2015; minimum SEER 14 (based on the region and application)
  - Rebates from utilities concerned about peak demand
  - Combined appliances

- **Improve operational efficiency of ACs and HPs**
  - Installation
  - Maintenance

Scope of the Study

❑ Two single-family houses

- House on a slab; air ducts in unconditioned space

  Duct leakage: 0 % - 50 % of the supply air flow rate
- House with a basement; air ducts in conditioned space

❑ Heat pump

- Equipment sizing: 90 % − 200 % of load calculations
- Indoor coil airflow: - 36 % − 28 % of design airflow
- Refrigerant charge: -30 % − 30 % (undercharge and overcharge)
- Non-condensable gases: 10 %, 20 %
- Electrical voltage: 92 %, 108 %, 125 % of the rated voltage
- Expansion device mismatched (TXV, cooling): - 60 %, - 40 %, - 20 %

❑ Five climates

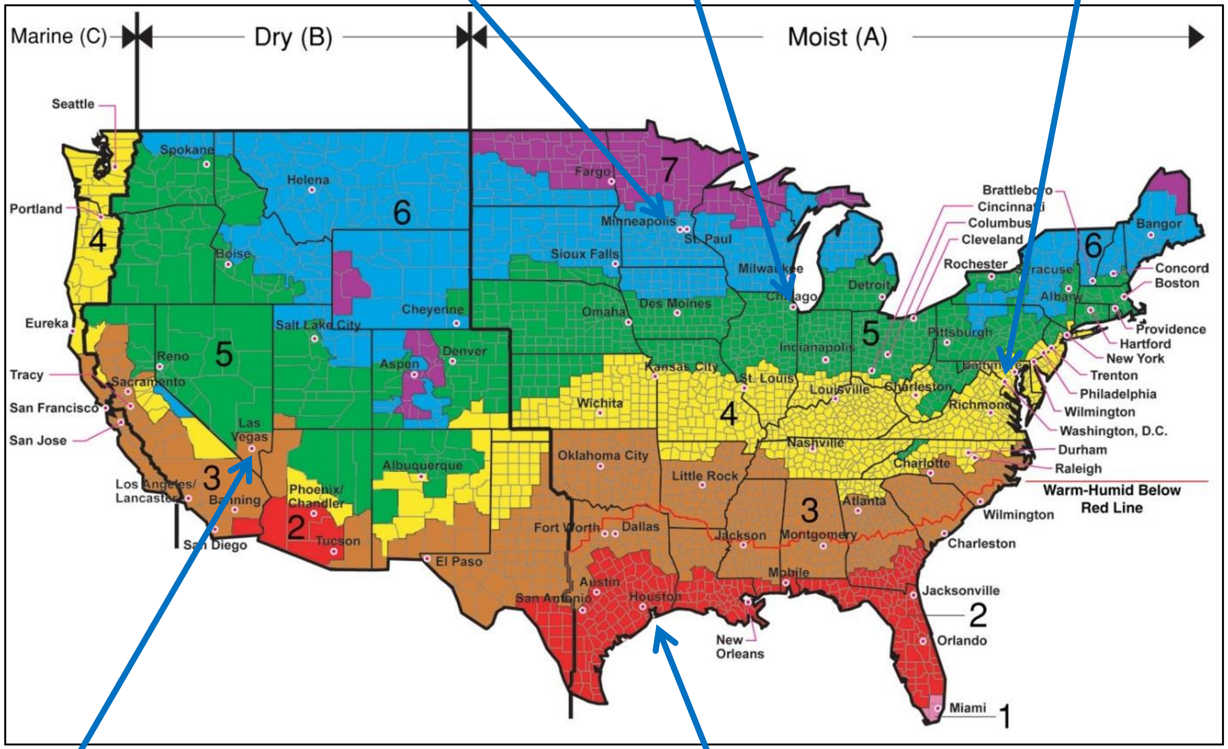
Hot-humid, Hot-dry, Mixed, Heating dominated, Cold

IECC Climate Zone Map

Minneapolis
2.5 ton
(24.4/21.1) ˚C (76/70) ˚F

Chicago
2.5 ton
(24.4/21.1) ˚C (76/70) ˚F

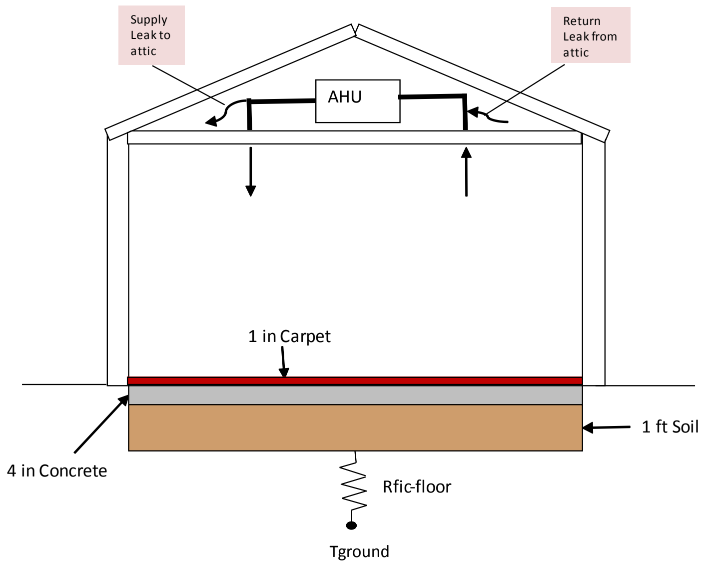
Washington, DC
2.5 ton
(24.4/21.1) ˚C (76/70) ˚F

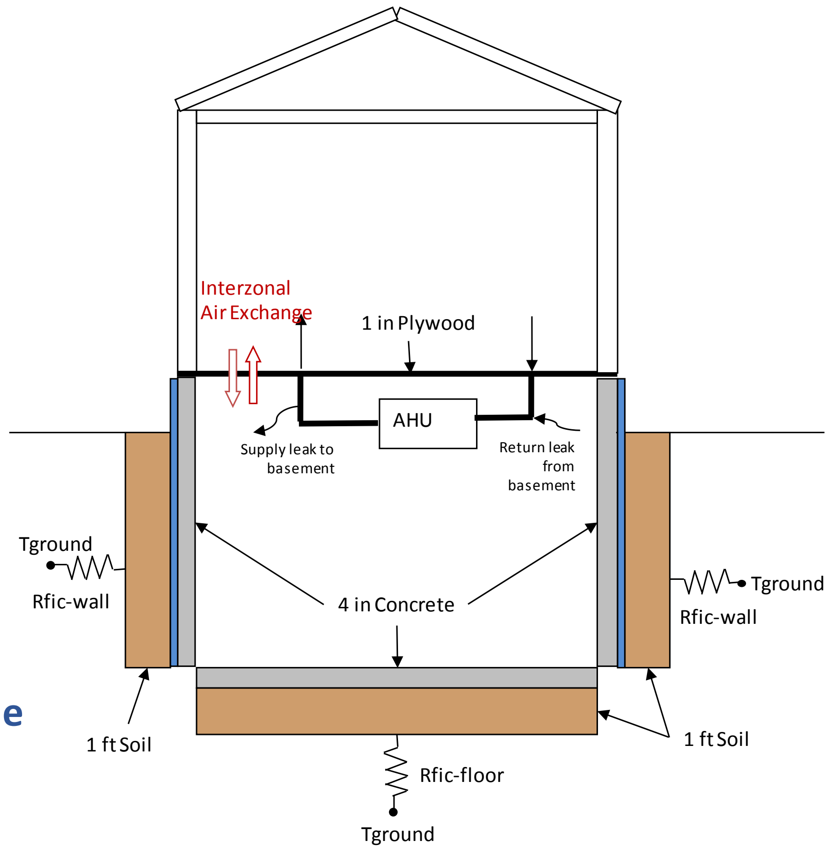


Las Vegas
3.5 ton
(25.6/22.2) ˚C (78/72) ˚F

Houston
3 ton
(25.6/22.2) ˚C (78/72) ˚F

Modeling of Single-Family Houses





Building envelope model based on Type 56 multi-zone building model (TRNSYS)

- Heat loss and gains through building walls, roof and floor
- Solar gains through windows
- Interactions between multiple zones (house, attic, rooms)
- Scheduled internal sensible and moisture loads for people, equipment, etc.
- Interactions with the heating, ventilation, and air-conditioning equipment
- Scheduled set points for temperature and humidity.

Home's HERS Index Score 100

Modeling of a Heat Pump

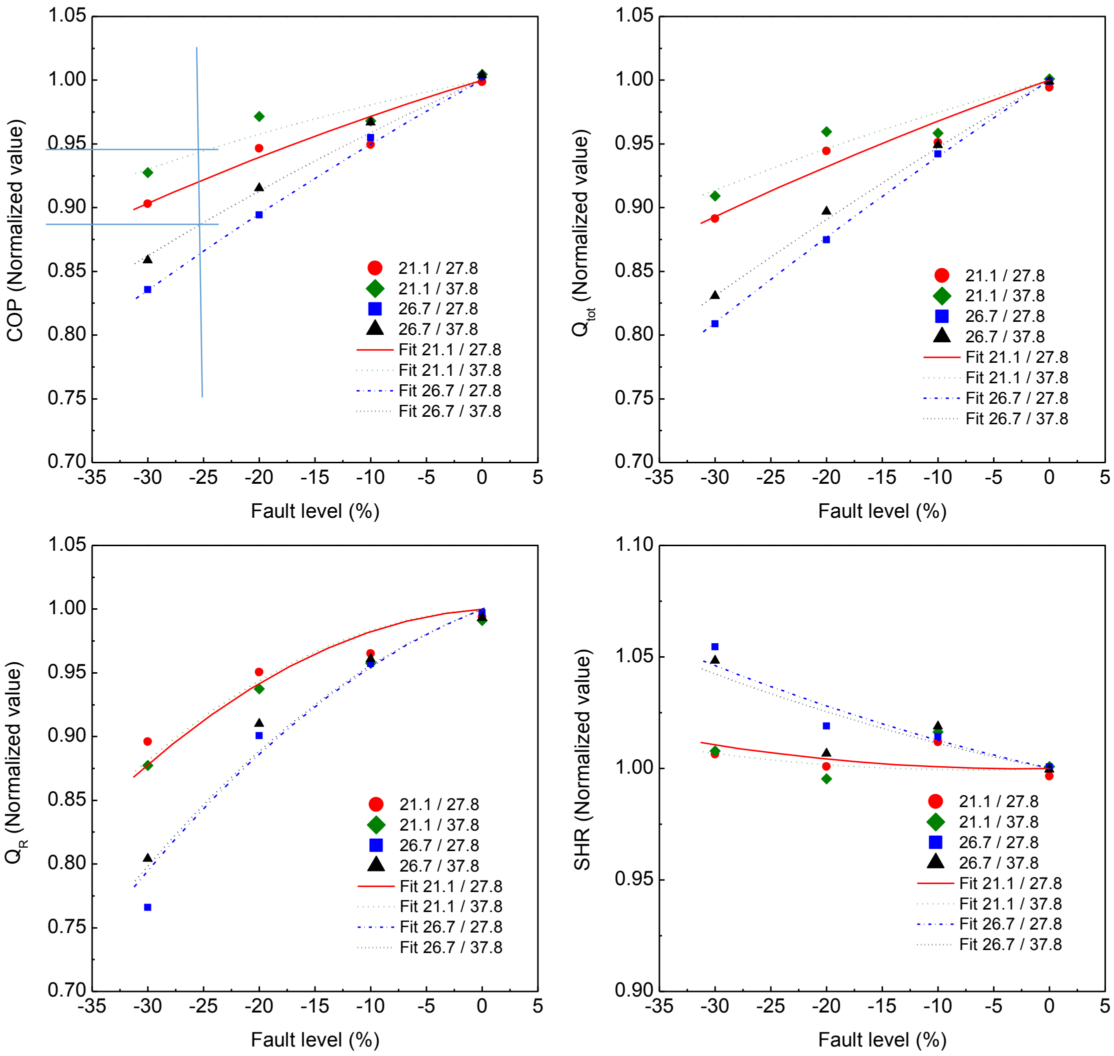
- **Heat Pump 13 SEER, single-speed, TXV**
  - 375 cfm/ton, 0.5 W/cfm, fan in AUTO (cycles) [50.3 L/kJ, 1.06 W/(L/s)]
  - Heat pump model from EnergyGauge model
    - COP
    - Total capacity
    - Refrigerant-side capacity
    - Sensible heat ratio (cooling only)
    - Outdoor section power
    - Heat pump total power

- **Dimensionless parameters for representation of faulty operation**

$$Y = \frac{COP_{fault}}{COP_{no-fault}} = 1 + (a_1 + a_2 T_{ID} + a_3 T_{OD} + a_4 F)F$$

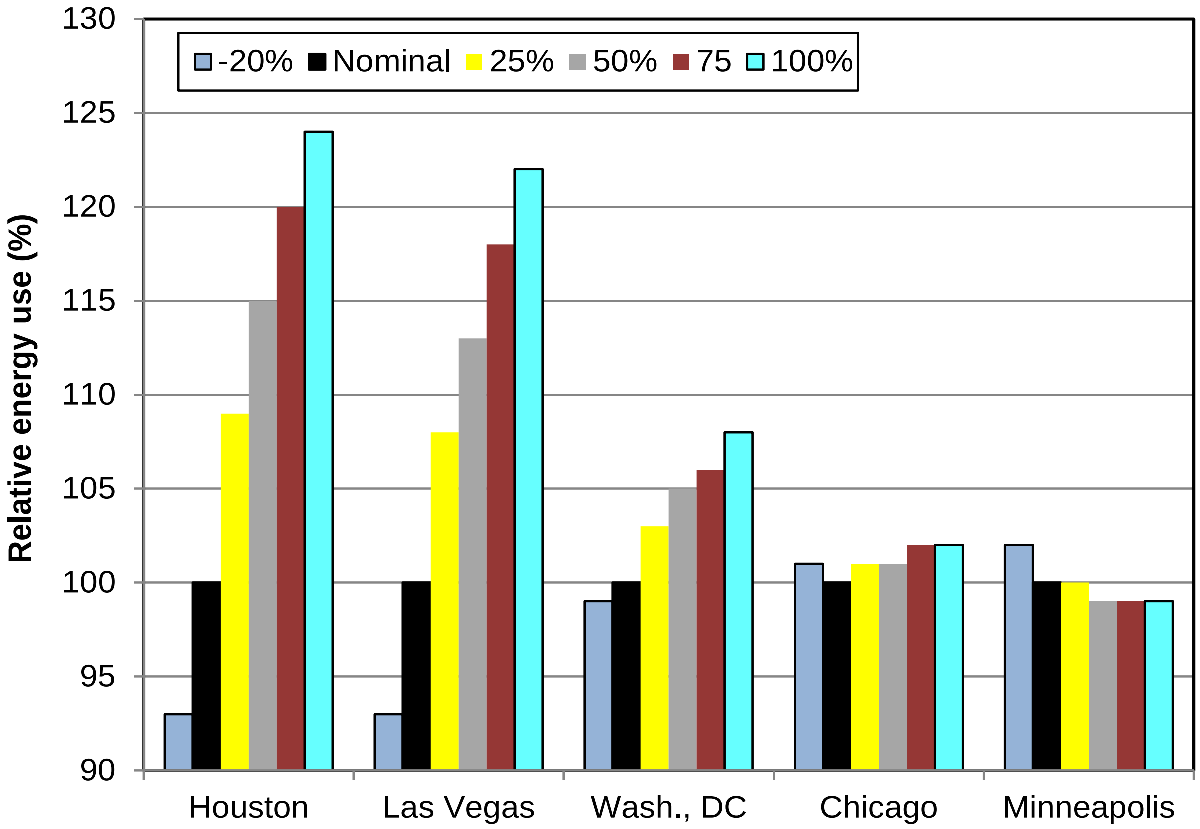
Refrigerant Undercharge

Cooling Mode



Heat Pump Sizing

Slab-on-grade house; fixed ducts

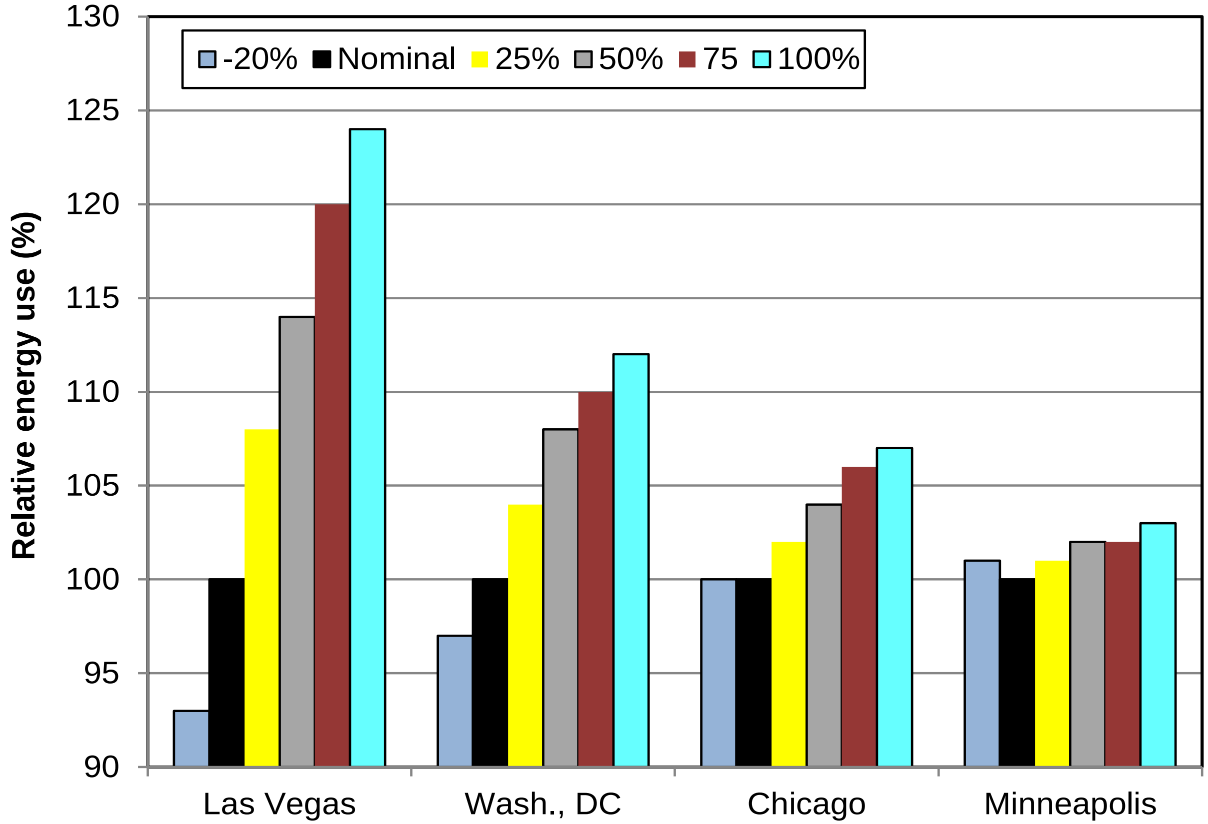


10 % duct leakage rate assumed

Factors: (a) Increased sizing increases cycling, which reduces COP ↘
(b) Increased sizing makes indoor fan work against higher external static pressure ↘ which increase duct leakage ↘
(c) Shorted runtimes reduce duct leakage ↗
(d) Increased heating capacity reduces the use of backup heat ↗

Heat Pump Sizing

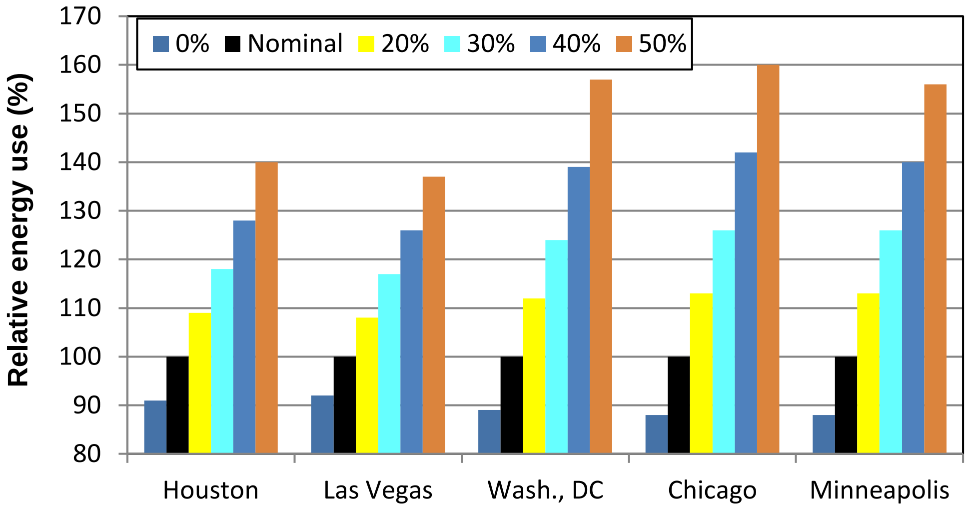
Basement house; fixed ducts



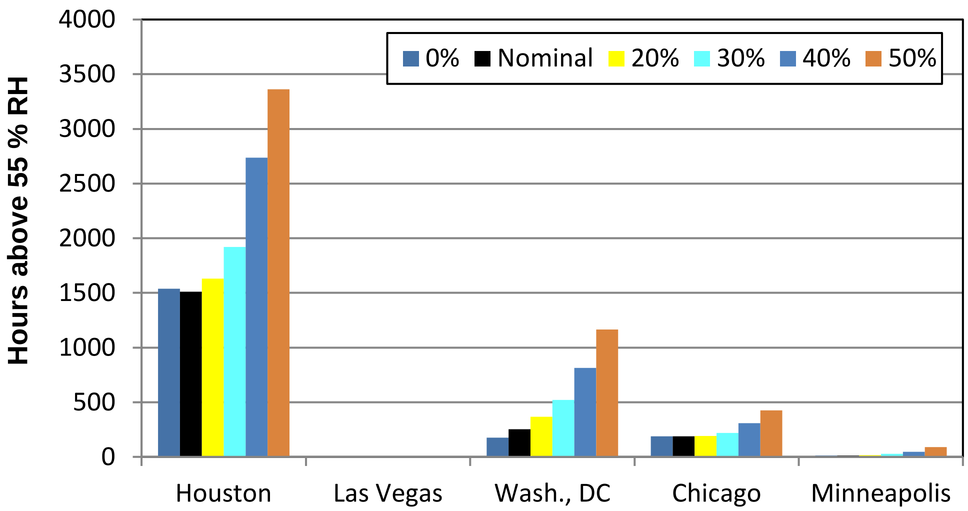
Factors: (a) Increased sizing cycling reduces COP ↘
(b) Increased sizing makes indoor fan work against higher external static ↘
(c) Increased heating capacity reduces the use of backup heat ↗

Duct Leakage

Slab-on-grade house

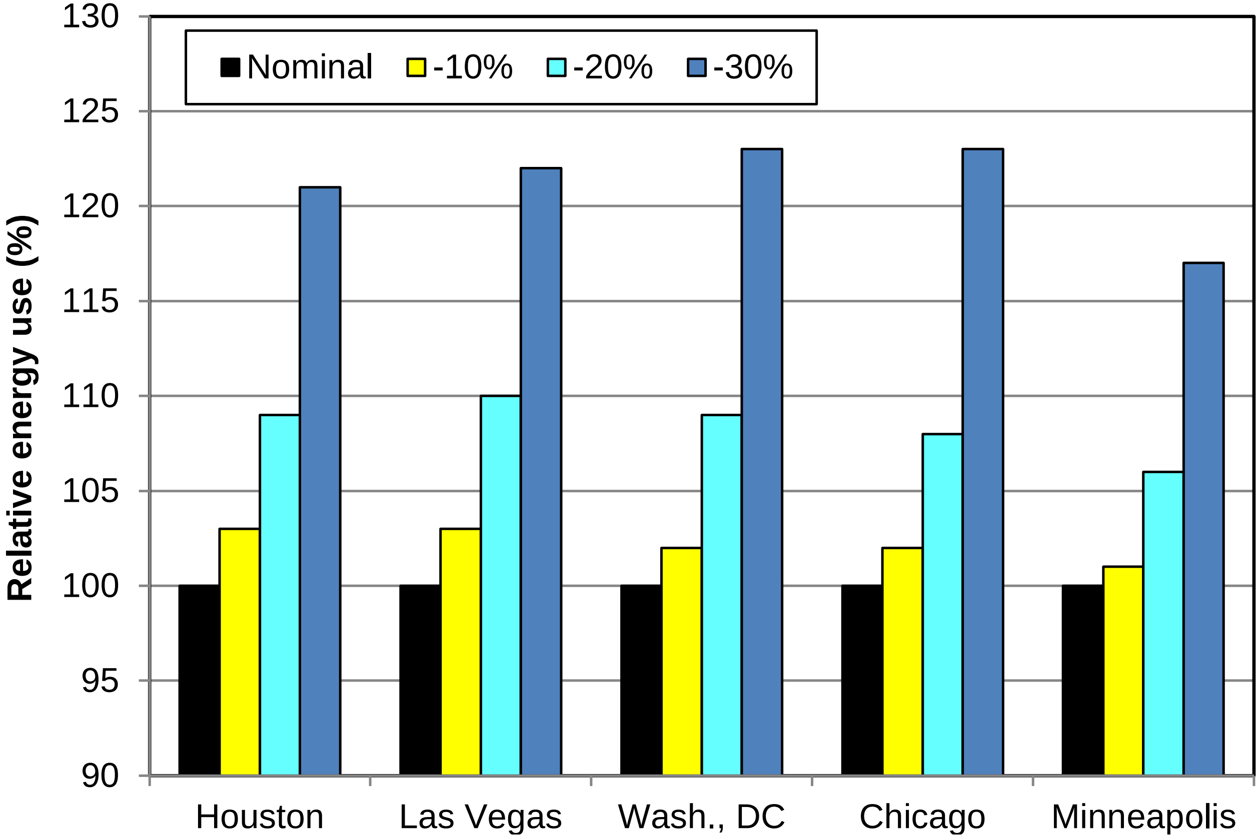


Significant increase in hours above 55 % RH in Houston



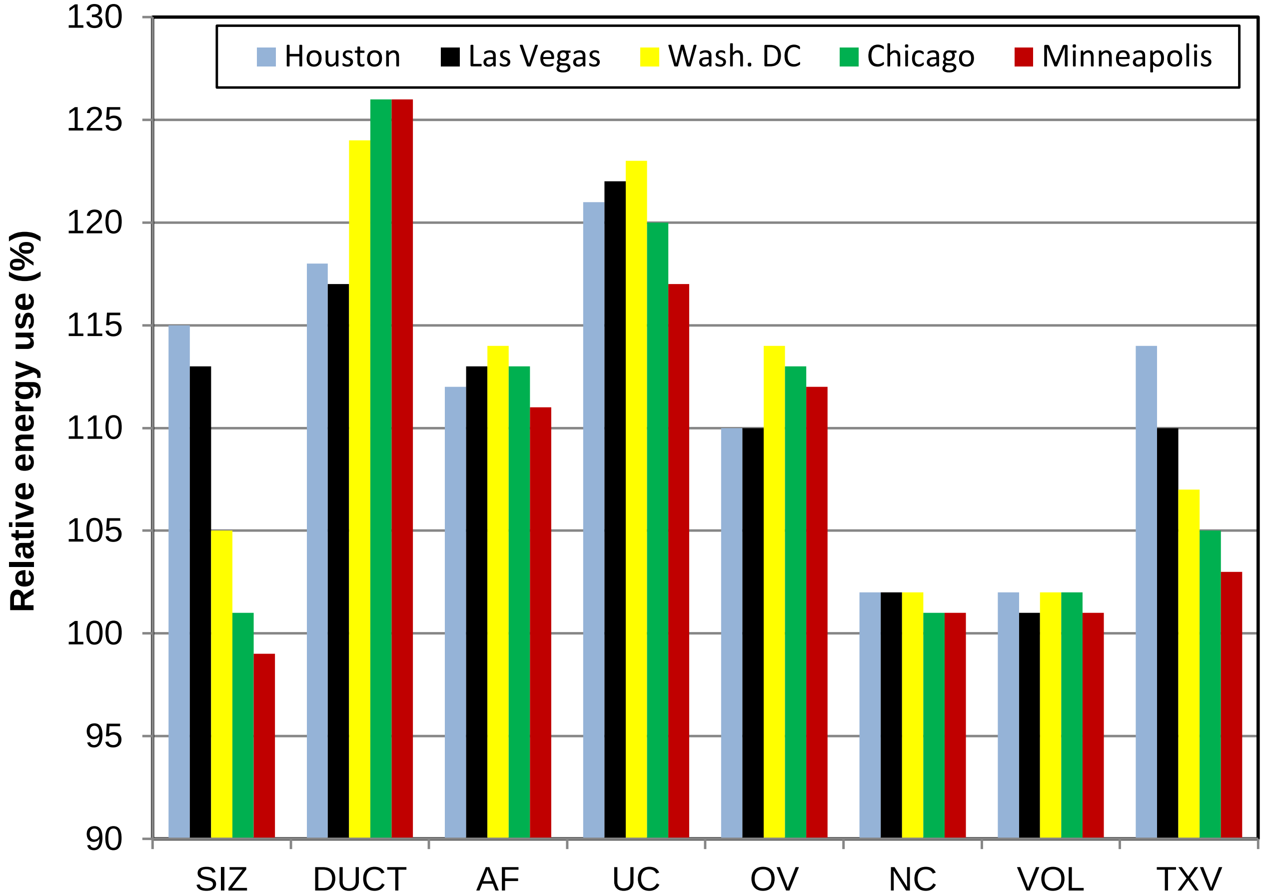
Refrigerant Undercharge

Slab-on-grade house



Single Faults Overview

Slab-on-grade house



Fault level (%)	50	30	- 30	30	30	10	8	-40

Simulated Dual Faults

Slab-on-grade house

Cooling and heating

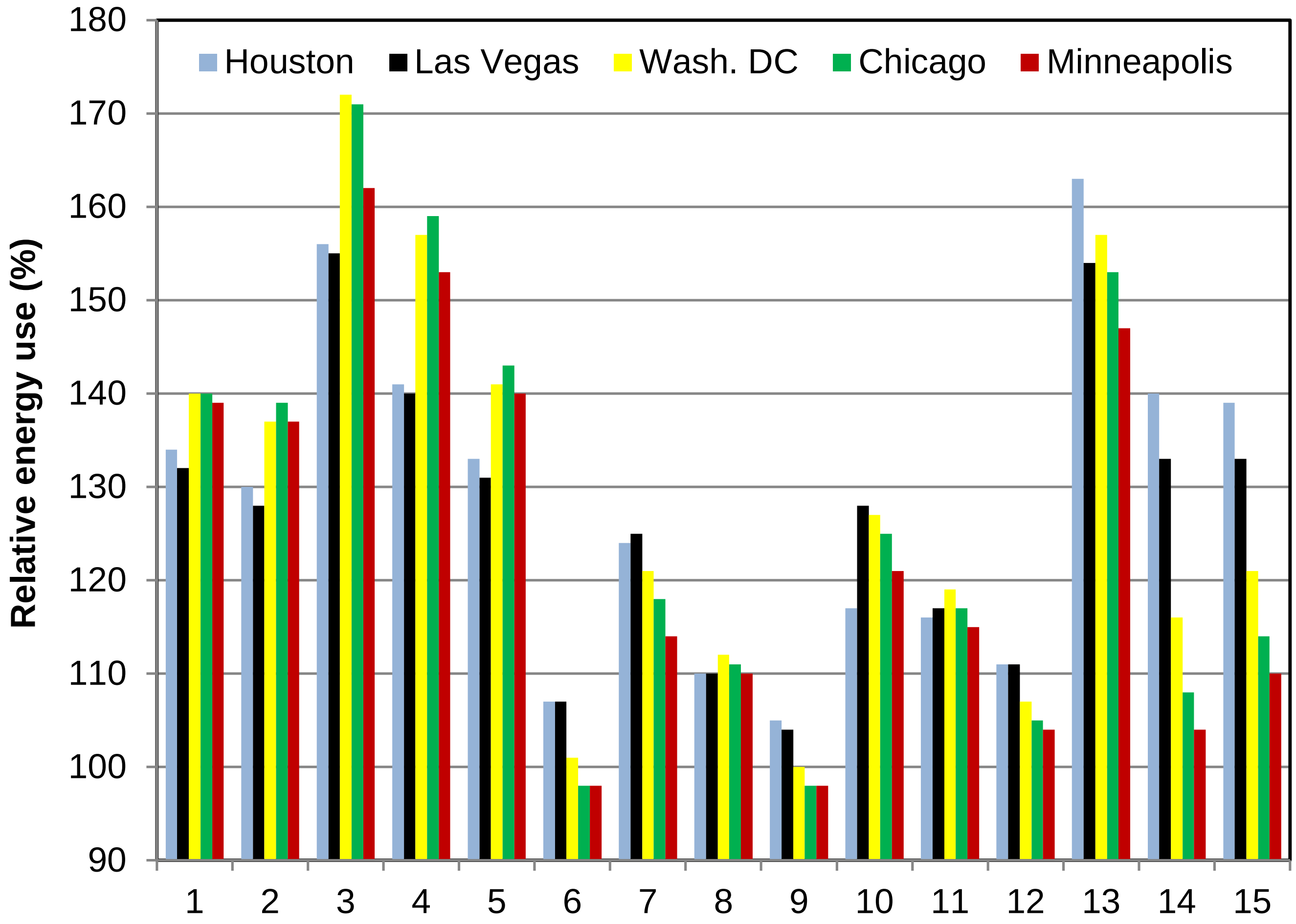
Fault set #	Fault A (moderate & worst level)[a]	Fault B (moderate & worst level)	Effect on energy use
1	Duct leakage (20 %, 40 %)	Oversize[b] (25 %, 50 %)	A+B
2	Duct leakage (20 %, 40 %)	Indoor coil airflow (-15 %, -36 %)	< A+B
3	Duct leakage (20 %, 40 %)	Refrigerant undercharge (-15 %, -30 %)	A+B or > A+B
4	Duct leakage (20 %, 40 %)	Refrigerant overcharge (15 %, 30 %)	A+B
5	Duct leakage (20 %, 40 %)	Non-condensables (10 %, 20 %)	A+B
6	Oversize[b] (25 %, 50 %)	Refrigerant undercharge (-15 %, -30 %)	A+B
7	Oversize[b] (25 %, 50 %)	Refrigerant overcharge (15 %, 30 %)	A+B
8	Oversize[b] (25 %, 50 %)	Non-condensables (10 %, 20 %)	A+B
9	Indoor coil airflow (-15 %, -36 %)	Refrigerant undercharge (-15 %, -30 %)	< A+B
10	Indoor coil airflow (-15 %, -36 %)	Refrigerant overcharge (15 %, 30 %)	< A+B
11	Indoor coil airflow (-15 %, -36 %)	Non-condensables (10 %, 20 %)	< A+B

Cooling only

Fault set #	Fault A (moderate & worst level)[b]	Fault B (moderate & worst level)	Effect on energy use
12	Duct leakage (20 %, 40 %)	Cooling TXV undersizing (-20 %, -60 %)	A+B
13	Oversize[c] (25 %, 50 %)	Cooling TXV undersizing (-20 %, -60 %))	A+B
14	Indoor coil airflow (-15 %, -36 %)	Cooling TXV undersizing (-20 %, -60 %)	< A+B

Dual Faults

Slab-on-grade house



The worst probable levels of faults used

Conclusions

- Effect of different installation faults is similar for a slab-on-grade house and basement house except the duct leakage fault.
- Effect of different installation faults is similar in different climates except:
  - Duct leakage; significant increase of indoor RH hot & humid climate
  - Heat pump sizing with undersized air duct; in heating-dominated increased fan power is compensated by a reduction in backup heat
  - Undersized cooling mode TXV; little effect in heating-dominated climate
- Most influential faults: duct leakage, refrigerant undercharge, heat pump with undersized duct, low indoor air flow, and refrigerant overcharge.
- Effect of simultaneous faults can be additive (DUCT & NC), weaker (AF & UC), or stronger (DUCT & UC).
- The study did not consider the impact on human comfort, indoor air quality, noise generation, equipment reliability, the cost of ongoing maintenance.

Bibliography

Source document:

Domanski, P.A., Henderson, H.I., Payne, W.V., 2014. Sensitivity Analysis of Installation Faults on Heat Pump Performance

NIST Technical Note 1848

National Institute of Standards and Technology, Gaithersburg MD. http://dx.doi.org/10.6028/NIST.TN.1848

QUESTIONS?

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