Evaluating the Potentials of Variable Air Volume Systems in North American Houses

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Topics to cover

- Background
- Objective
- Significance of Research
- Research Steps
- Survey
- Simulation
- Economic Analysis
- Future Work
- Q & A

Background
Deficiency of systems used today

Most houses in Canada use single zone constant air volume (CAV) systems

Typically results in inefficient heating or cooling due to the differences in thermal load in different spaces throughout the house:

- Solar heat gain varies with different orientation
- Size of room
- Appliance gain

Also, heating and cooling loads of these houses are generally overestimated because:

- Unoccupied spaces are conditioned

Background cont'd

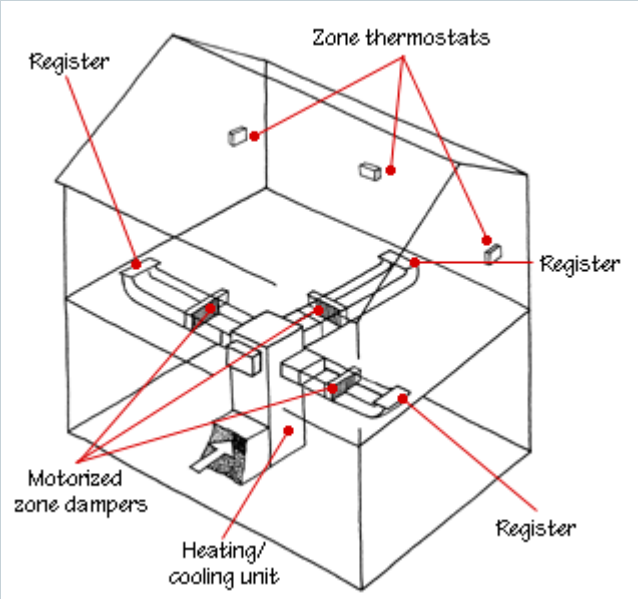
Having one ON/OFF switch based on one thermal sensor for the entire house
Result is:

- Reduction of the thermal comfort of occupants
- Wasting energy used for over - conditioning spaces

As an alternative... Multi-zone system

- Multi-zone systems use dampers in ductwork

that open and close as needed based on each zone's thermostat settings. When a zone is at the selected temperature, and doesn't need to be heated or cooled, the dampers close to save energy and maximize comfort elsewhere.



Source: www.remodelguide.com

Objective

- Survey
  - Investigate on today's problem by conducting a full scale survey
  - Identify current systems' deficiency (severity and factors)
- Simulation
  - Potential to mitigate current system deficiency
  - Analyze energy use reduction and associated economics of switching conventional CAV systems with VAV types in single family residential buildings

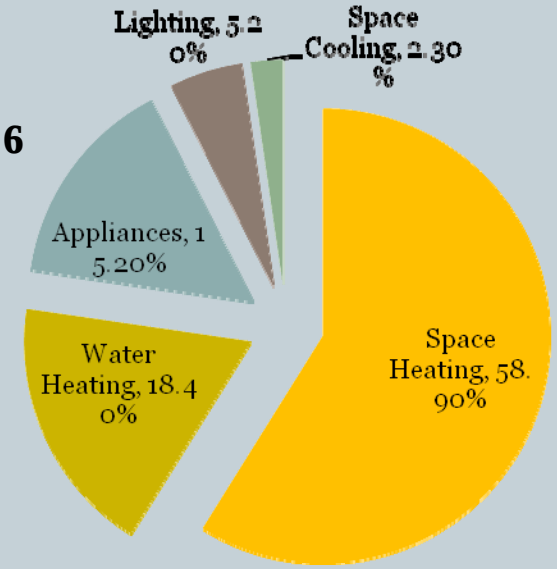
Significance of Research

Huge potential of efficiency improvement in HVAC systems

- Total energy saving of 17% can be achieved with HVAC systems operating with combining five energy management control (EMC) functions (Huang et al., 2005)
- Study in UK - Total energy saving of 20% can be achieved with improving the control of the heating systems (Liao, 2003)
- Study in USA – On average, 24% to 29% of energy savings can be achieved with installing high-efficiency equipment in houses (Lucas et al., 2007)

Significance of Research

- Reduce energy consumptions…
  - **6,800,000 single detached houses in Canada by 2006**
  - **Each house consumes 62.2 GJ/year for space heating**



  - **A mere reduction of 5% per household with using a more efficient heating system would save 21,370,000GJ/year or 21,370TJ/year**
    - Equivalent to the yearly output of 534 1.5MW coastal wind turbines
    - Enough to power an additional 350,000 houses every year

- Potentially improve controllability and hence thermal comfort

Research steps

1. Investigate on problems with existing single zone systems
   - Survey on occupant behaviour and control of thermal environment in houses in Ontario, Canada
2. Simulation – Single-zone vs. Multi-zone systems
   - Case study – an existing house in Toronto
3. Economic Analysis
   - Internal rate of return

Survey

- Conducted between March-May 2009
- Responses gathered: 400 responses

Contained questions on the following topics:

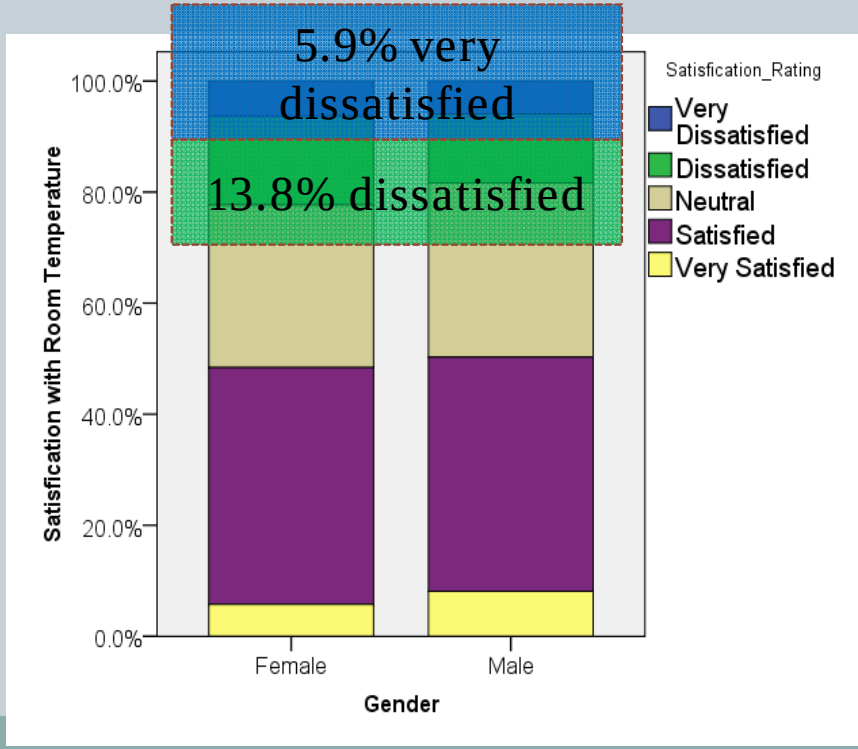
- Background information on occupant (Age and sex of the respondent, type of the dwelling etc.)
- Satisfaction rating on room temperature
- Occupant control on heating system i.e. thermostat settings and use of supplementary heating equipments
- Occurrence of overheating and overcooling

- SPSS v.16 (statistical analysis tool)
- Statistical tests (non-parametric):
  - Group differences on ordinal (rank) tests:
    - Mann-Whitney (two independent samples)
      - Satisfaction rating with genders
    - Kruskal-Wallis (three or more independent samples)
      - Satisfaction rating with different house types
  - Strength of ordinal data sets:
    - Spearman's rho test
      - Satisfaction rating vs. Perceived Control

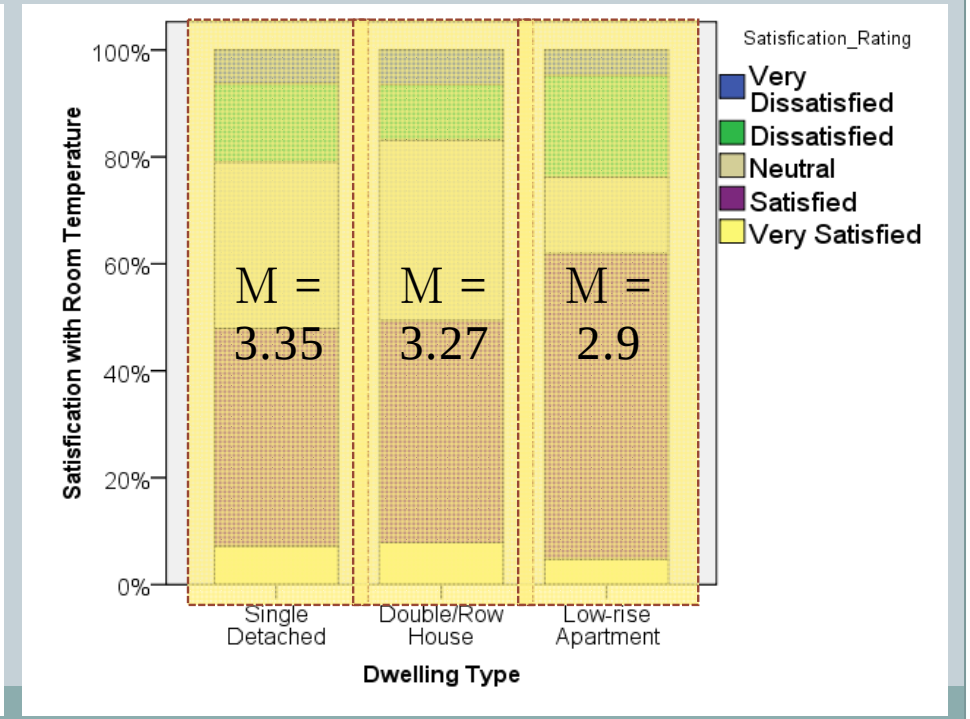
Survey Results

Satisfaction with room temperature was rated with a scale from 1 to 5 with 1 being very dissatisfied and 5 being very satisfied.

- Satisfaction with room temperature for male and female respondents



- Satisfaction with room temperature for different house types

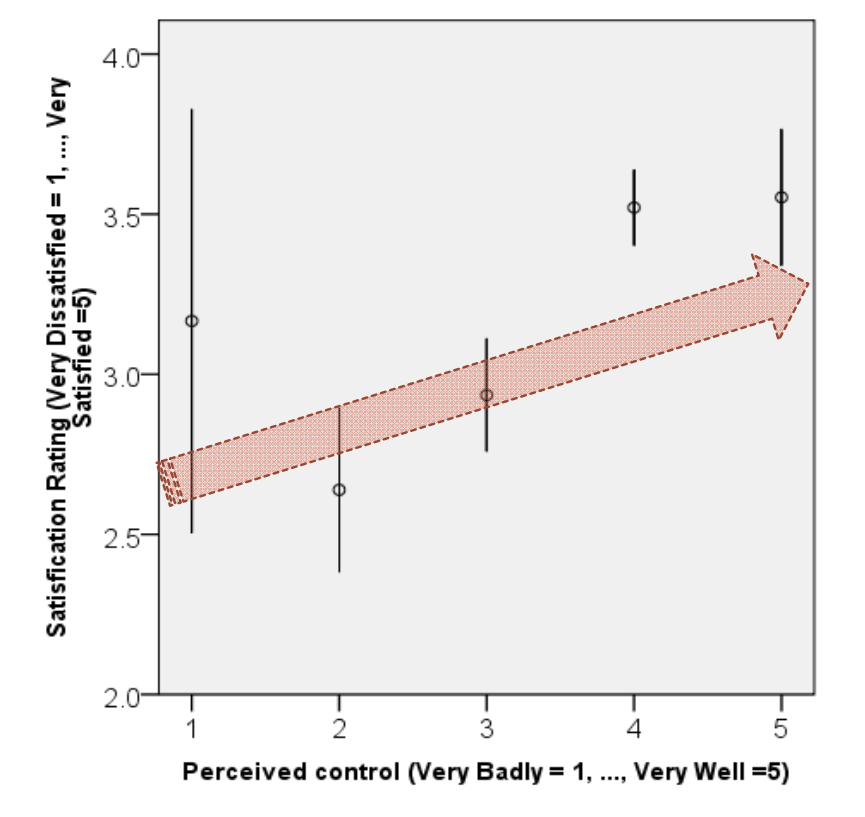


Survey Results cont'd

Relationship between satisfaction with room temperature and perceived control over room temperature

Perceived control with room temperature was rated with a scale from 1 to 5 with 1 being very badly and 5 being very well

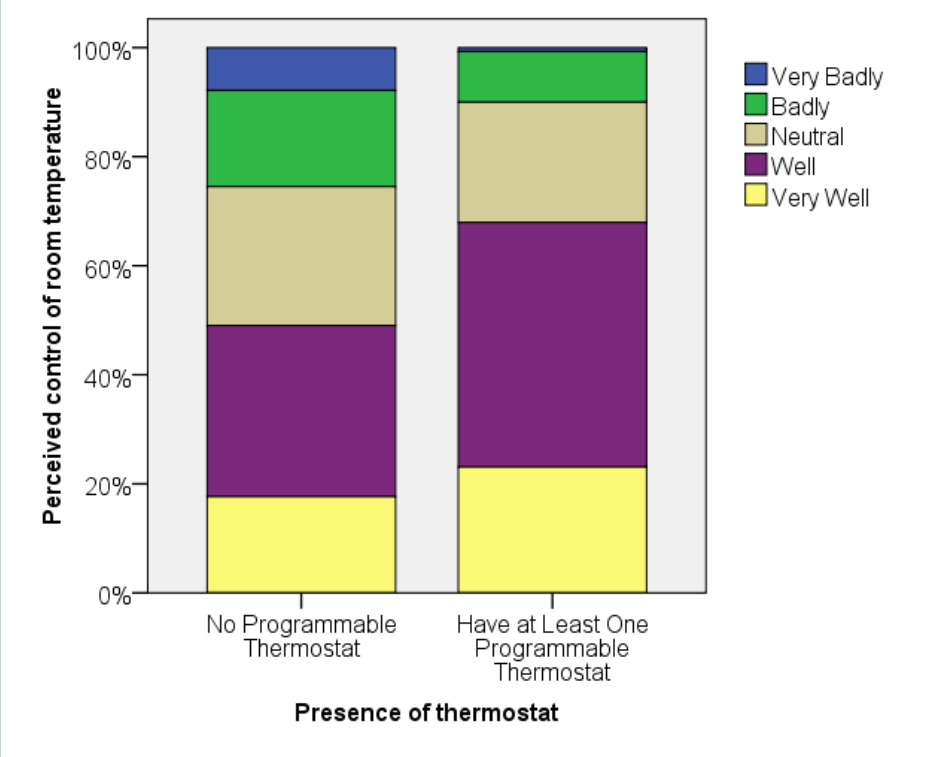
- Moderate correlation between perceived control and thermal comfort
- Spearman's rho test - the correlation coefficient is 0.323.



Survey Results cont'd

Satisfaction with room temperature in houses with houses with and without programmable thermostats

- The level of perceived control is much lower in houses without programmable thermostats
- The mean values for houses with and without programmable thermostats are 3.8 and 3.33
- Mann-Whitney U test: exact p = 0.008 (two-tailed) - statistically significant
- Studies previously have shown the importance of individual control of temperature for thermal comfort and productivity



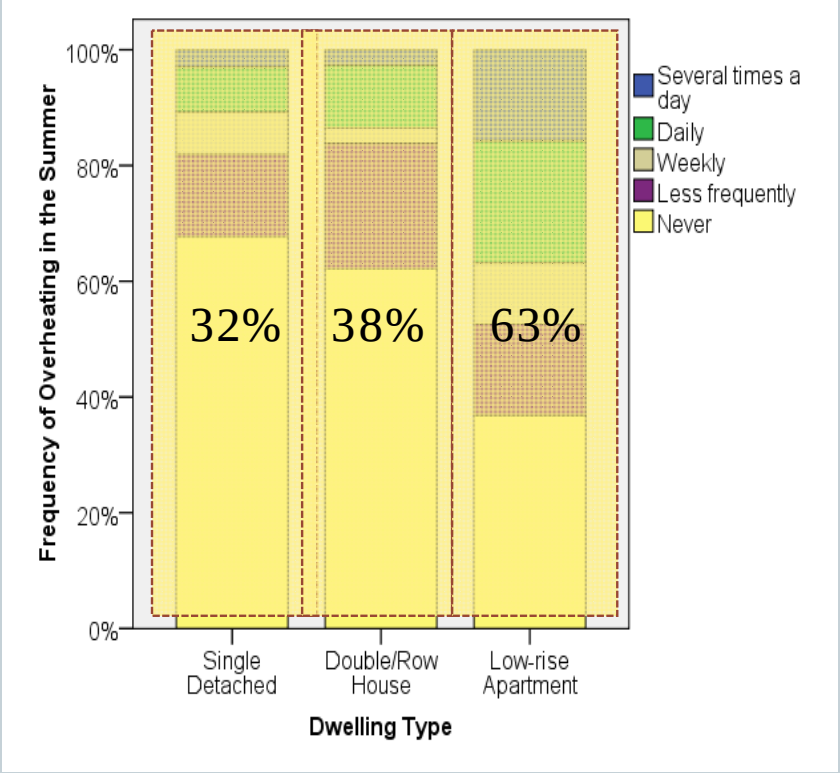
Survey Results cont'd

Frequency of overheating for different house types

- 36% experienced overheating
  - 37% of that experienced overheating daily and need to open their windows for ventilation

- Spearman's rho test - positive moderate correlation between overheating and overcooling frequency. The coefficient of correlation is 0.41.

- The occurrences of overheating vary amongst the different house types. Kruskal-Wallis test : exact p = 0.007 - statistically significant



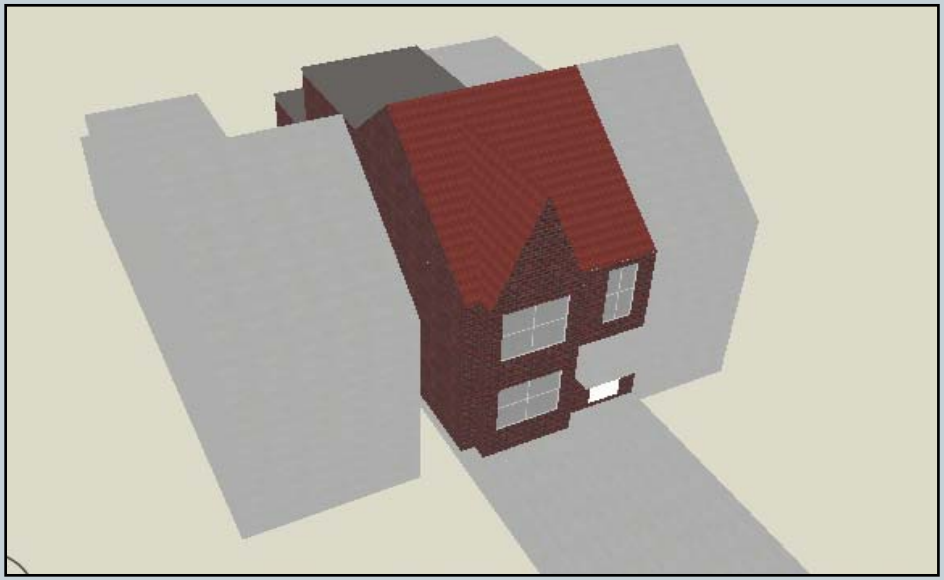
- Survey results show there exists a systematic problem with heating systems used today
  - Perceived control is much lower in houses with no thermostats
  - Positive correlation between perceived control and satisfaction
  - Overheating and overcooling is more predominant in houses with no thermostats, where perceived control is recorded to be lower

  → In need of an alternate heating and cooling system to alleviate systematic problems

Simulation

- DesignBuilder v2.0.4 (Whole building simulation program)
  - Based on EnergyPlus Simulation Engine, which features the capabilities of BLAST and DOE-2.1E

Case Study

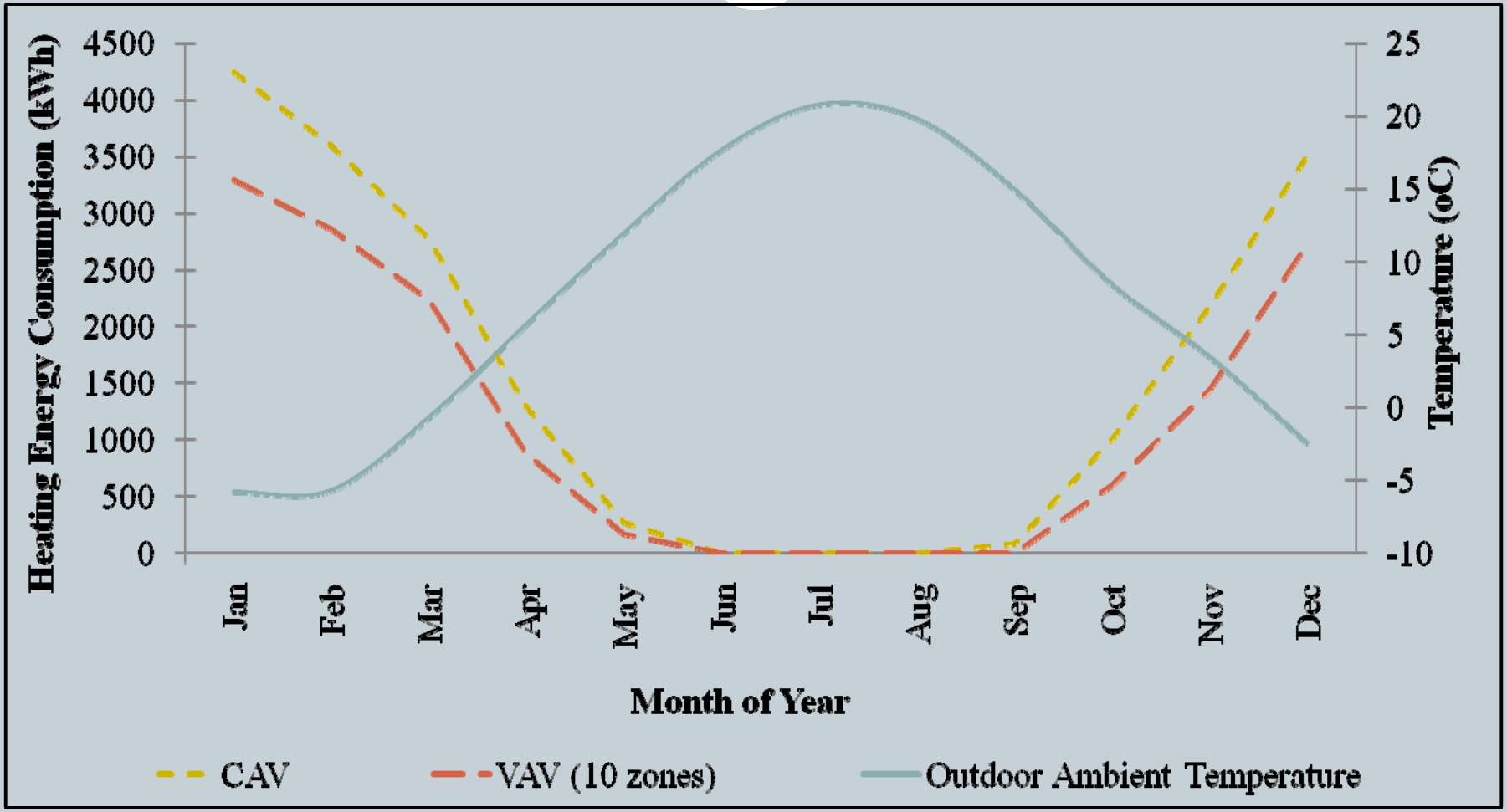


- Semi-detached house located in downtown Toronto (HDD ~3600)
- Approximately 215 m^2 (2130 ft^2)
- Occupied by two adults and two children
- No air-conditioning unit

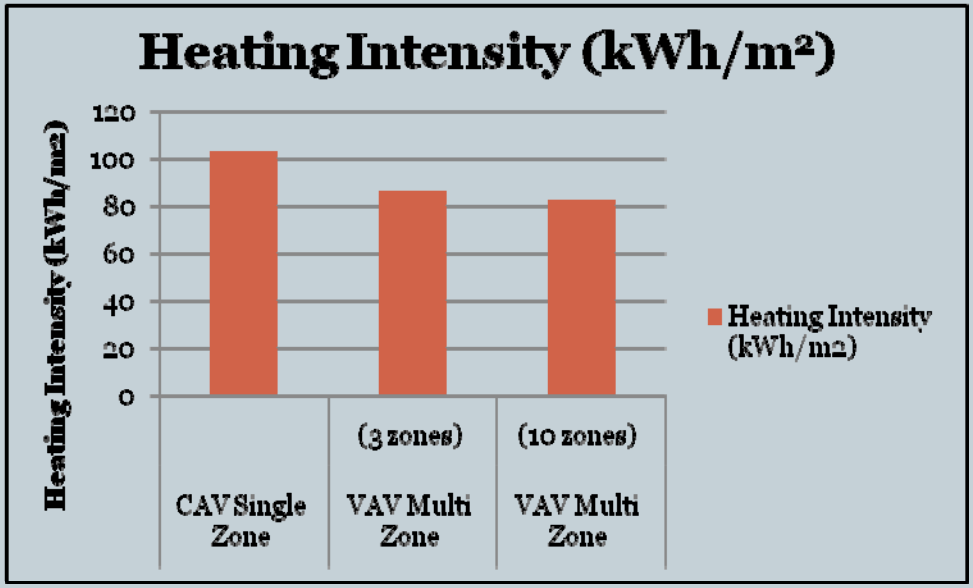
Scenarios

- Basecase – Single-zone system
  - Constant volume direct expansion based unitary HVAC system
  - The entrance area of the house acts as a control zone with a programmable thermostat placed at the zone
  - The set point and setback temperature is 22 ^{o}C and 20 ^{o}C for heating
- Upgrade to multi-zone system (3- and 10- zones)
  - Utilizing the same central heating system with the single stage gas furnace, the house is divided into multiple control-zones with each zone having its own thermostat
  - Air flow to each zone is controlled by a mechanical damper in the duct to regulate the zone's temperature
  - The multi-zone heating system includes an electronic controller and a by-pass damper located at the central Air Handling Unit (AHU)
  - The controller communicates with the thermostats in each zone to control main air supply from the central AHU unit.

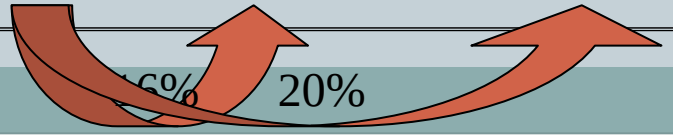
Simulation Results



Simulation Results cont'd



Energy Requirement	CAV Single Zone	VAV Multi Zone (3 zones)	VAV Multi Zone (10 zones)
Space Heating Energy Use (kWh)	22 176	18 593	17 775
Heating Intensity (kWh/m^2)	103	86.5	82.6



Economic Analysis

Cost to upgrade:

3-zone VAV system

Description	Costs
Multi-Zone System Controller	$463.14
Programmable Zone Thermostat (x3)	$150.00
6" Low Pressure Dampers (x3)	$424.08
12" Barometric Bypass Damper	$89.90
Wiring between controller and damper	$149.42
Installation and labour	$2 000.00
Total	$3 276.54

10-zone VAV system

Description	Costs
Multi-Zone System Controller	$463.14
Programmable Zone Thermostat (x10)	$500.00
6" Low Pressure Dampers (x10)	$1 413.60
12" Barometric Bypass Damper	$89.90
Wiring between controller and damper	$149.42
Installation and labour	$4 000.00
Total	$6 616.06

Economic Analysis

Annual Cost of Fuel

	CAV Single Zone	VAV Multi Zone (3 zones)	VAV Multi Zone (10 zones)
Natural Gas ($)	$777.09	$614.08	$581.76
Electricity ($)	$301.08	$338.40	$335.67

Internal Rate of Return

	CAV to VAV (3 zones)	CAV to VAV (10 zone)
Cost Saving from Natural Gas ($)	163.01	195.32
Cost Saving from Electricity ($)	-37.31	-34.59
Investment ($)	3 276.54	6 616.06
Total Annual Cost Saving from Energy ($)	125.69	160.73
Internal Rate of Return (%)	2%	0%

Undesirable rate of return. But analysis did not take fuel price inflation into account.

Economic Analysis

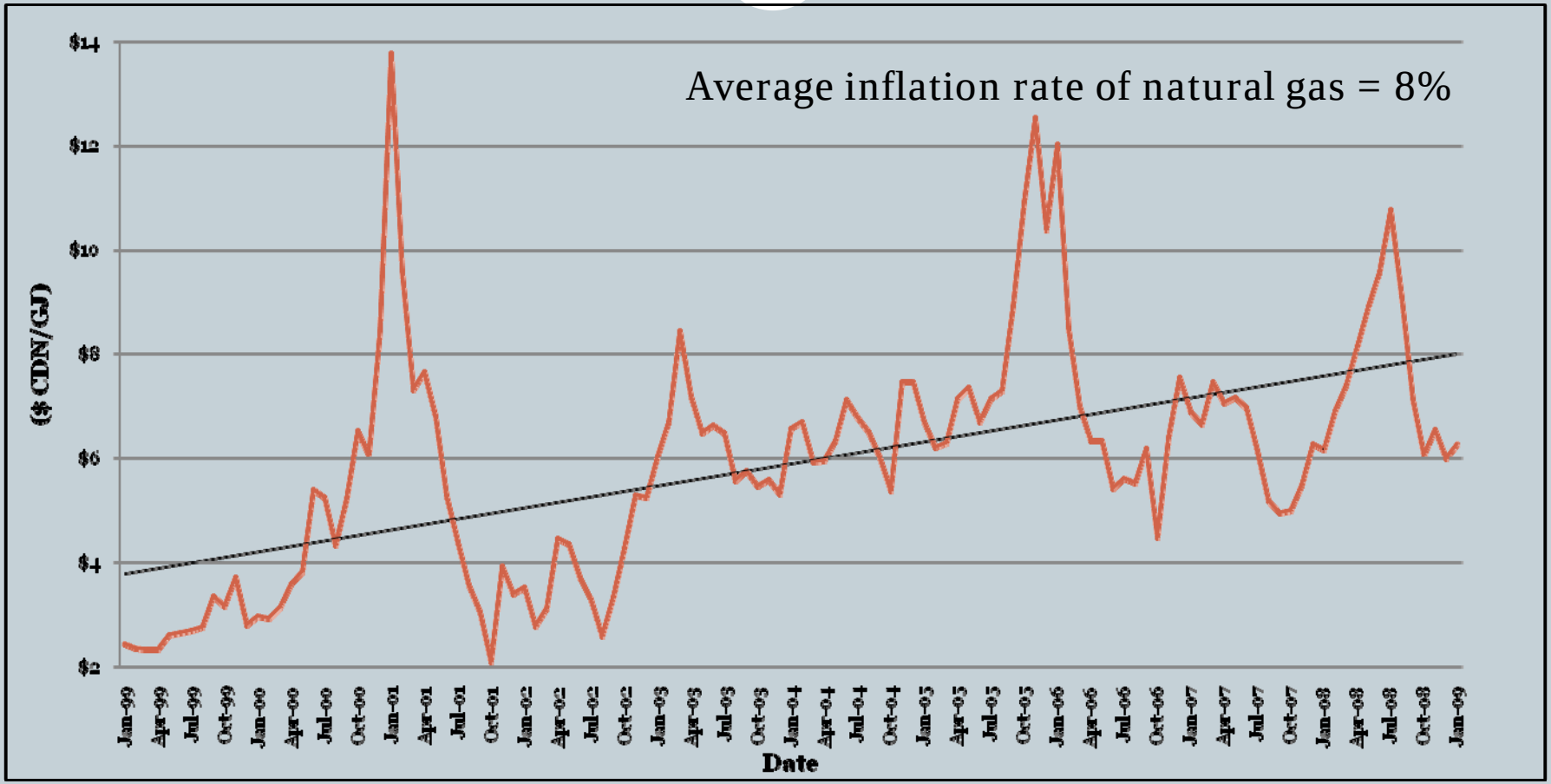


Figure - Historical natural gas price in Canada (NRCan, 2009)

Scenario: Consider fuel price will remain constant for the next 3 years due to the current economic slowdown. After 3 years, the cost of natural gas will rebound to $\$0.60/m^3$, and an inflation of 1% and 4% will follow on the fuel price.

Case	IRR
Three Zone VAV 4% inflation	8%
Ten Zone VAV 4% inflation	5%
Three Zone VAV 1% inflation	5%
Ten Zone VAV 1% inflation	3%

Conclusion and Future Work

- Conclusion
  - VAV can conserve considerable amount of energy
  - Economic analysis for energy performance upgrades should take fuel price inflations into account
    - Might be worth investing on provided with the on-going energy crisis
- Future Work
  - Simulation on thermal comfort levels
  - Simulation
    - MATLAB/Simulink
  - Validation of results
    - On-site experimentation

Thank you for your attention

Questions?