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# Review of Temperature and Humidity Control Technology for Air Conditioning and Heat Pump Systems

## Paper 2386

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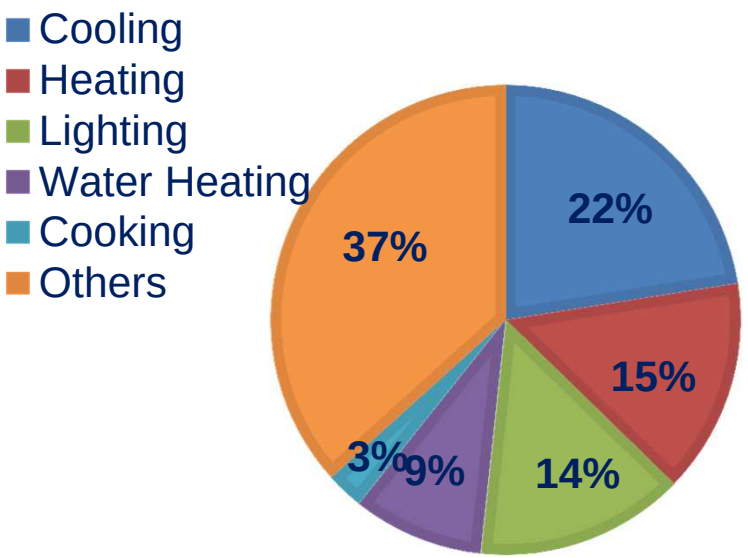
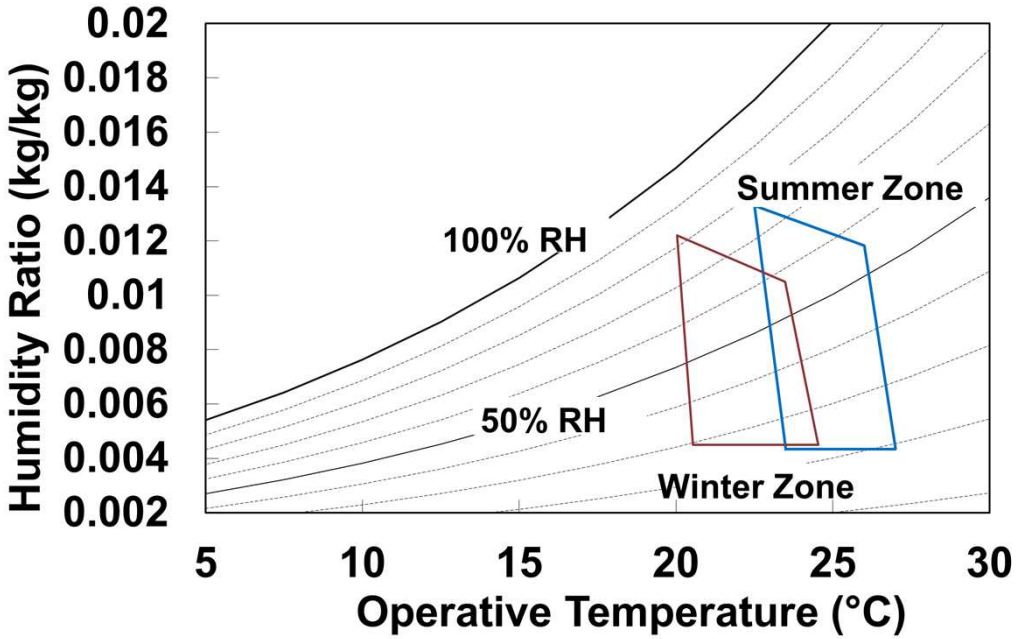
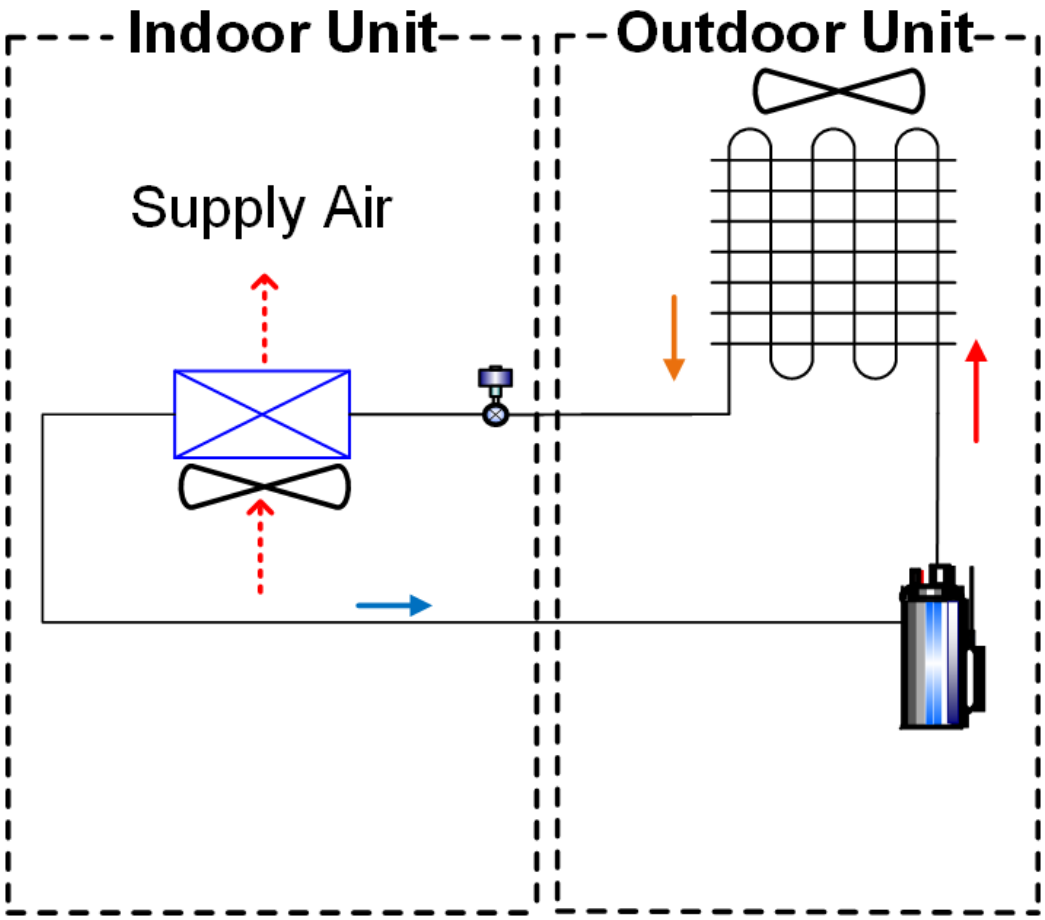
# Introduction



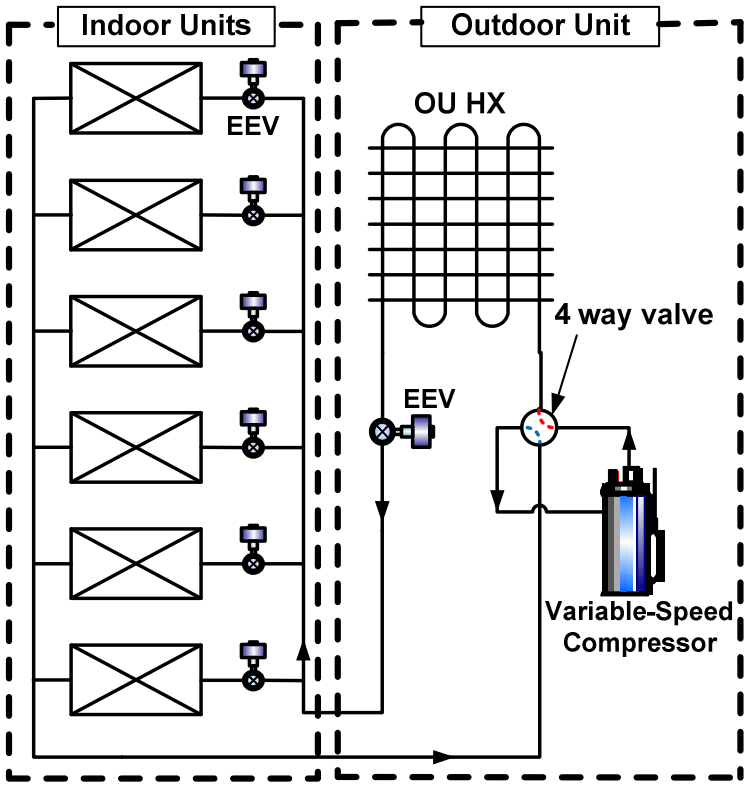

- **In 2010, US building sector (42 EJ) accounted for 41% of total primary energy consumption.**
- **Air conditioning system is a major contributor in the building sector (15.5 EJ).**
- **Improper control of air condition systems could lead to both huge energy waste and uncomfortable indoor condition, especially the temperature and humidity control.**

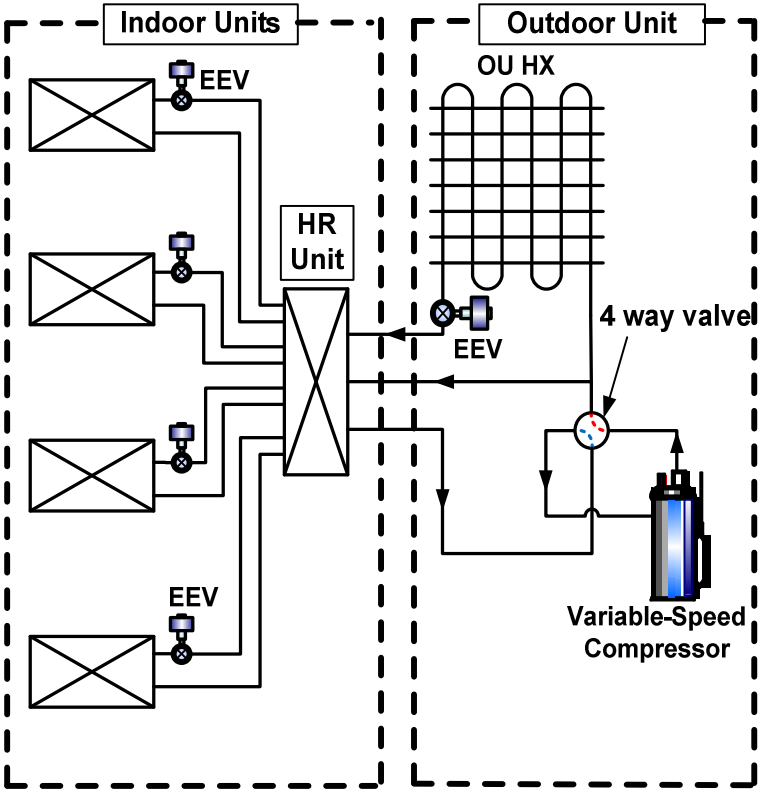
# Split System




- Outdoor unit includes:
  - Fan
  - Compressor
  - Air to refrigerant heat exchanger (Condenser)
- Indoor unit includes:
  - Fan (3~4 levels of speed)
  - Direct expansion (DX) coil
  - Expansion device (capillary tube or expansion valve).

# Variable Refrigerant Flow System



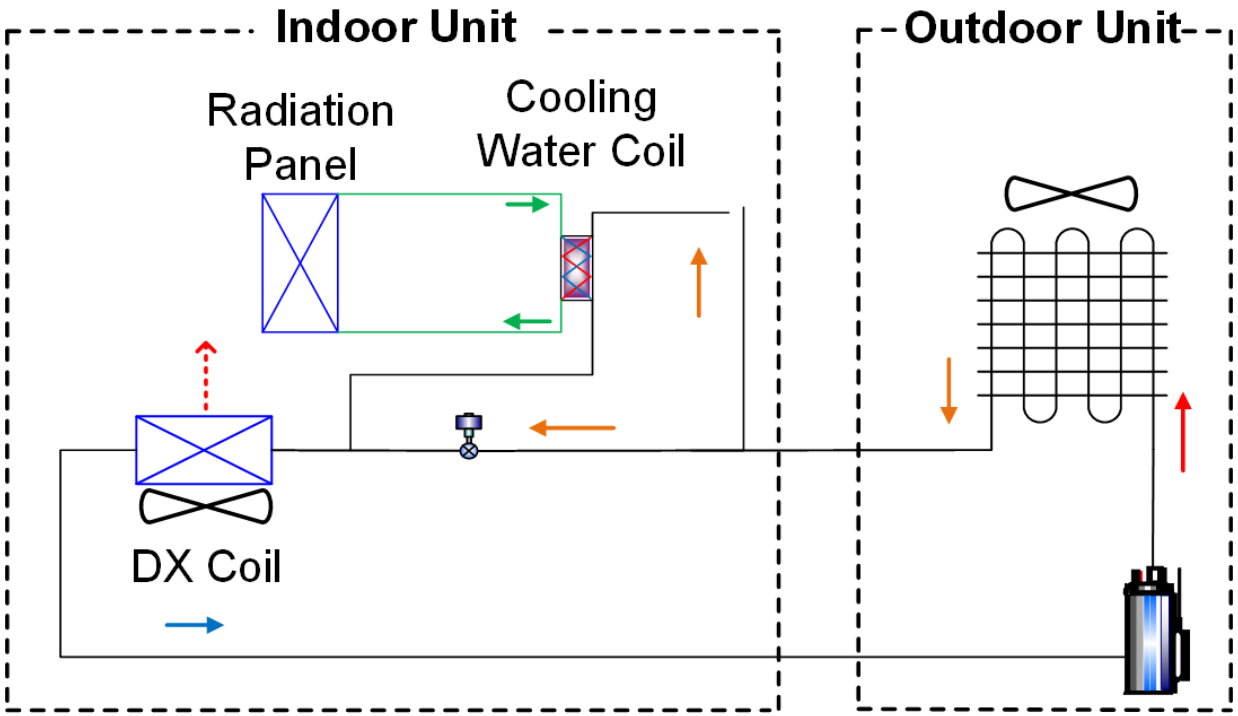

- Variable refrigerant flow (VRF) system provides precise control of the indoor units.
- HP-VRF provides either cooling or heating.
- HR-VRF can provide simultaneous cooling and heating.

# Split System Study

| Author (Year) | Location | Cooling Capacity (kW) | Concept |
|---|---|---|---|
| Han and Zhang (2011) | Shanghai | 12 | Use two evaporators and one radiation panel |
| Chu et al.(2005), Chu and Jong (2008) | Taipei | 14 | Use effective temperature to represent thermal comfort |
| Krakow et al. (1995) | N/A | N/A | Match apparatus SHF with room SHF |
| Li et al. (2006) | Hong Kong | N/A | |
| Li and Deng (2007a,2007b) | Hong Kong | 10 | |
| Sekhar and Tan (2009) | Singapore | 100 (Building) | |
| Li and Deng (2007c), Xu et al. (2009), Li et al. (2014) | Hong Kong | 10 | |
| Deng et al. (2009) | Hong Kong | 10 | |
| Huh and Brandemuehl (2008) | Miami | 106 (Building) | |
| Xu et al. (2008) | Hong Kong | 4 | |
| Qi and Deng (2008) | Hong Kong | 10 | |
| Qi and Deng (2009) | Hong Kong | 10 | |

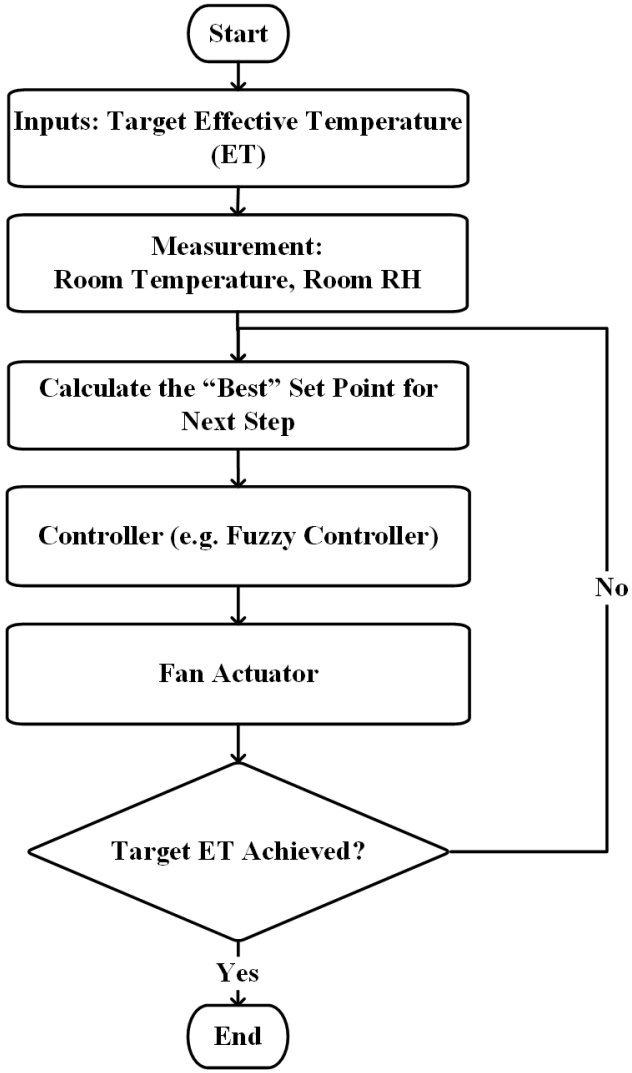
- **Category #1: Temperature and Humidity Control Separated**
- **Category #2: Temperature and Humidity Combined: Effective Temperature (ET)**
- **Category #3: Sensible and Latent Load Combined: Sensible Heat Factor (SHF)**

# Category #1



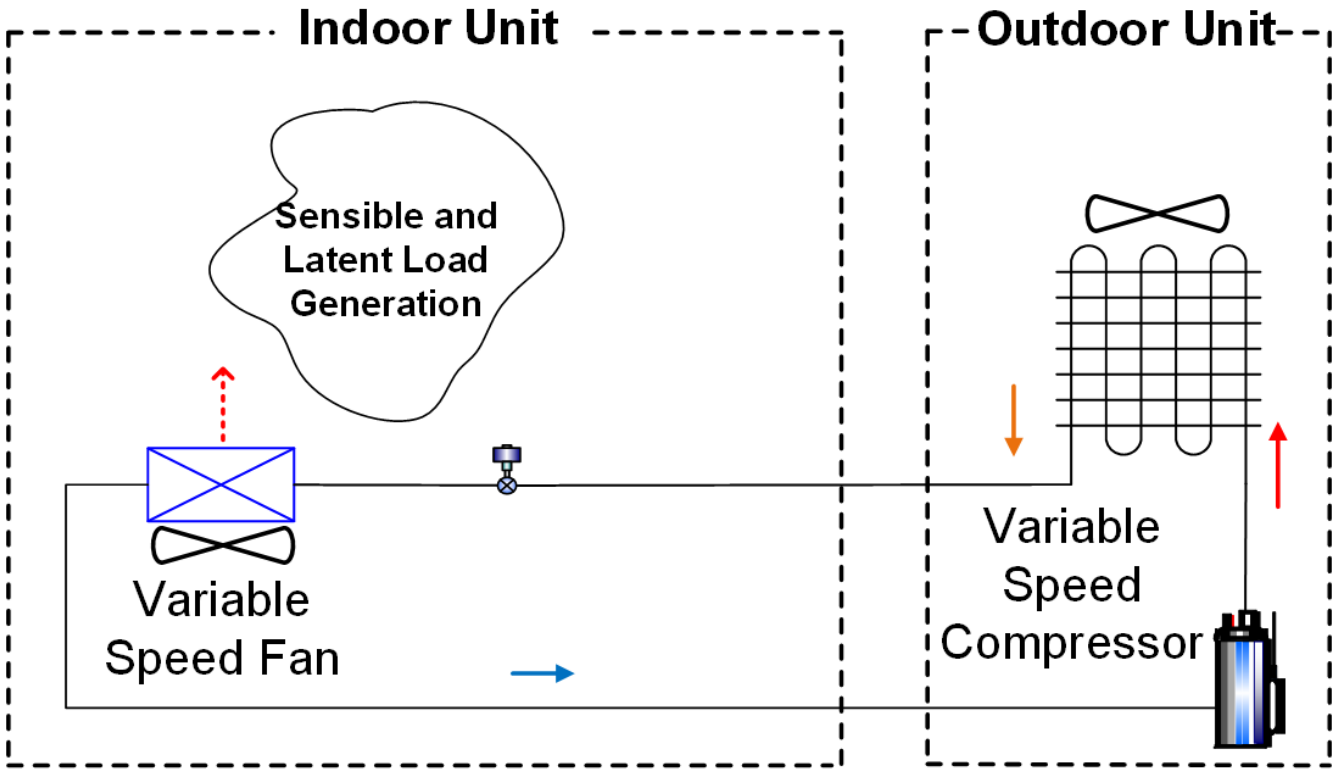

- **Two evaporators are used: one DX evaporator, one evaporator for chilled water.**
- **Water in radiation panel: cooling**
- **Supply air generated by DX coil: dehumidification**
- **Challenges: additional water loop and refrigerant-to-water coils**

# Category #2




- Occupant thermal comfort is translated into room ET.
- The "best " set point is defined as the room state:
  - Yields the desired room ET
  - Has the least enthalpy difference from the current room condition
- Controller accepts the "best" set point as inputs and generate control signal for fan speed.

# Category #3



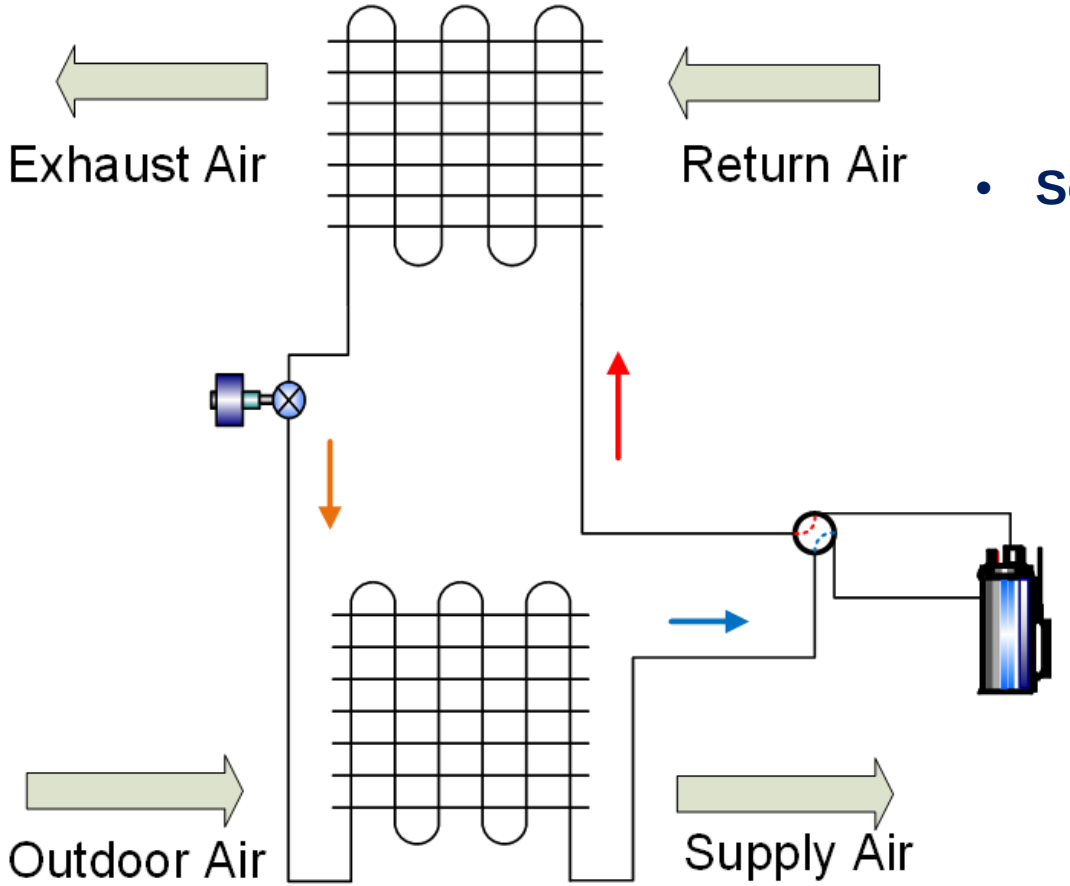

- From the load aspect, sensible heat factor (SHF) of the room is different from that of the apparatus in hot and humid region.
- Room SHF: 0.55~0.72 (Hong Kong, Summer Daytime)
- Apparatus SHF: 0.7~0.8
- In category #3, the goal is to match the apparatus SHF with room SHF.

# Category #3, Cont'd

| Author (Year) | Location | Cooling Capacity (kW) | Concept |
|---|---|---|---|
| Krakow et al. (1995) | N/A | N/A | **PID control of compressor and evaporator** fan to regulate unit SHF |
| Huh and Brandemuehl (2008) | Miami | 106 (Building) | Optimized energy consumption with thermal comfort constraints based on **compressor control, fan control** |
| Xu et al. (2008) | Hong Kong | 4 | Used **"High-Low" compressor speed control** instead of on/off control |
| Qi and Deng (2009) | Hong Kong | 10 | Used **MIMO** simultaneous control of **compressor speed and evaporator fan** speed. |

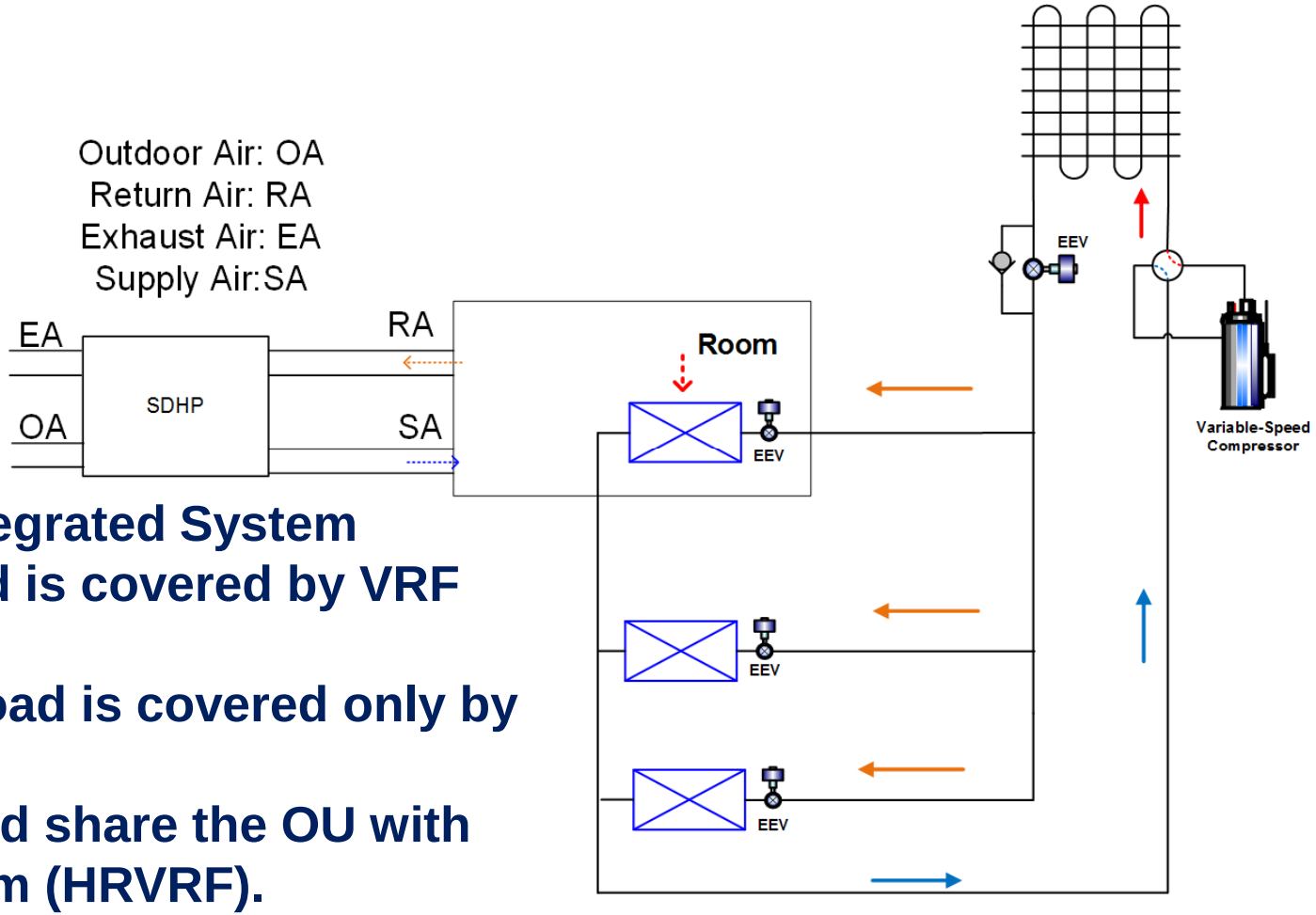
- **Compressor speed and evaporator fan speed are used to control the SHF of the indoor units.**
- **Challenges:**
  - **It needs to have a prediction of room SHF.**
  - **It is applicable only in a narrow room SHF range: 0.7~0.8.**

# Solid Desiccant Heat Pump




- **Sold Desiccant Heat Pump (SDHP)**
  - **It has desiccant material coated HXs as evaporator and condenser.**
  - **In evaporator, outdoor air is dehumidified.**
  - **It is able to switch the role of evaporator and condenser.**
  - **By periodic mode switch, it keeps a continuous operation.**

# Integrated SDHP and VRF System




- **VRF-SDHP Integrated System**
  - **Latent load is covered by VRF and SDHP.**
  - **Sensible load is covered only by VRF.**
  - **SDHP could share the OU with VRF system (HRVRF).**
  - **It ensures sufficient ventilation in the rooms.**

# Integrated SDHP and VRF System

| Authors (Year) | Type | # of IUs | OU Cooling Capacity (kW) | Operation Modes | Note | Location |
|---|---|---|---|---|---|---|
| Aynur et al. (2010a) | HP | 8 | 28 | Cooling Only | Field test | Maryland, US |
| Aynur et al. (2010b) | HP | 8 | 28 | Heating Only | Field test | Maryland, US |
| Jiang et al. (2014a) | HP | 6 | 28 | Cooling Only | Field test | Shanghai, China |
| Jiang et al. (2014b) | HP | 6 | 28 | Heating Only | Field test | Shanghai, China |
| Jiang et al. (2013, 2014) | HP | 6 | 28 | Cooling and Heating | Simulation | Shanghai, China |

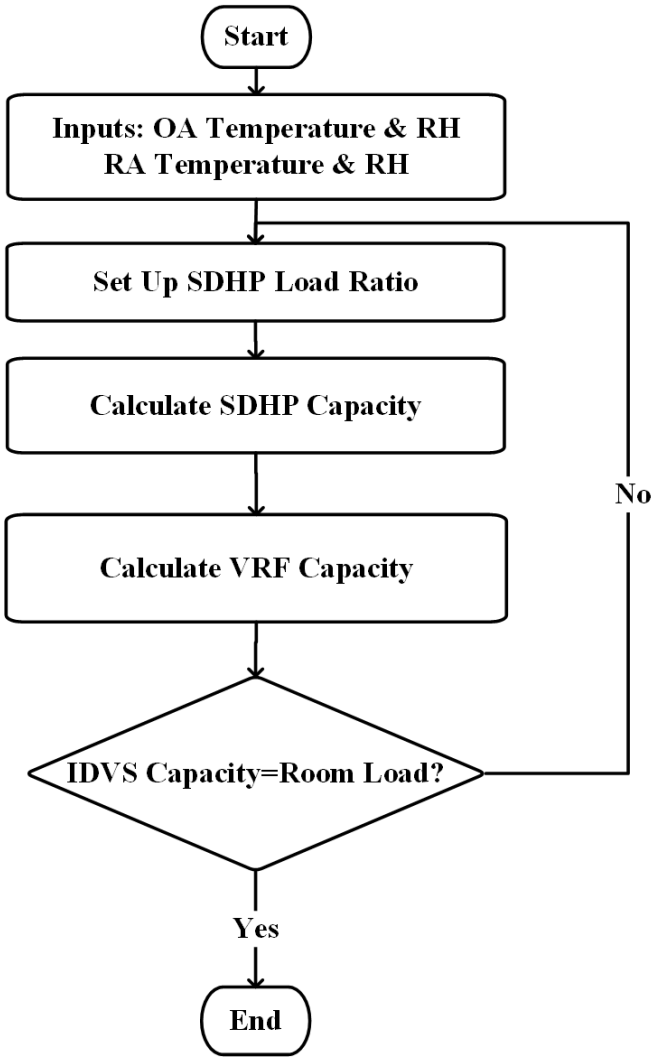
- **In these studies, integrated SDHP and VRF systems (IDVS) include:**
  - **A standalone HPVRF system**
  - **A SDHP system**
- **These studies include following operation modes or baseline systems:**
  - **VRF system with heat recovery ventilation (VRF-HRV)**
  - **IDVS : non-ventilated mode**
  - **IDVS : only ventilation**
  - **IDVS : dehumidification/humidification (cooling/heating season)**

# IDVS Experimental Study

- **IDVS Dehumidification Mode Highlights:**
  - **VRF delivers 78.9% of accumulated cooling capacity.**
  - **Room is kept within thermal comfort zone during 99.8% of the testing period.**
  - **Seasonal energy consumption is 40.6% higher than non-ventilated mode due to operation of SDHP.**
  - **The seasonal performance factor is 7.2% higher than non-ventilated mode.**
  - **60% of the testing period, room $CO_2$ concentration is within 400-450 ppm.**

- **IDVS Compared with VRF-HRV**
  - **IDVS saves 17.2% energy.**
  - **IDVS increases COP by 25.7% in cooling season.**
  - **IDVS provides more latent capacity.**

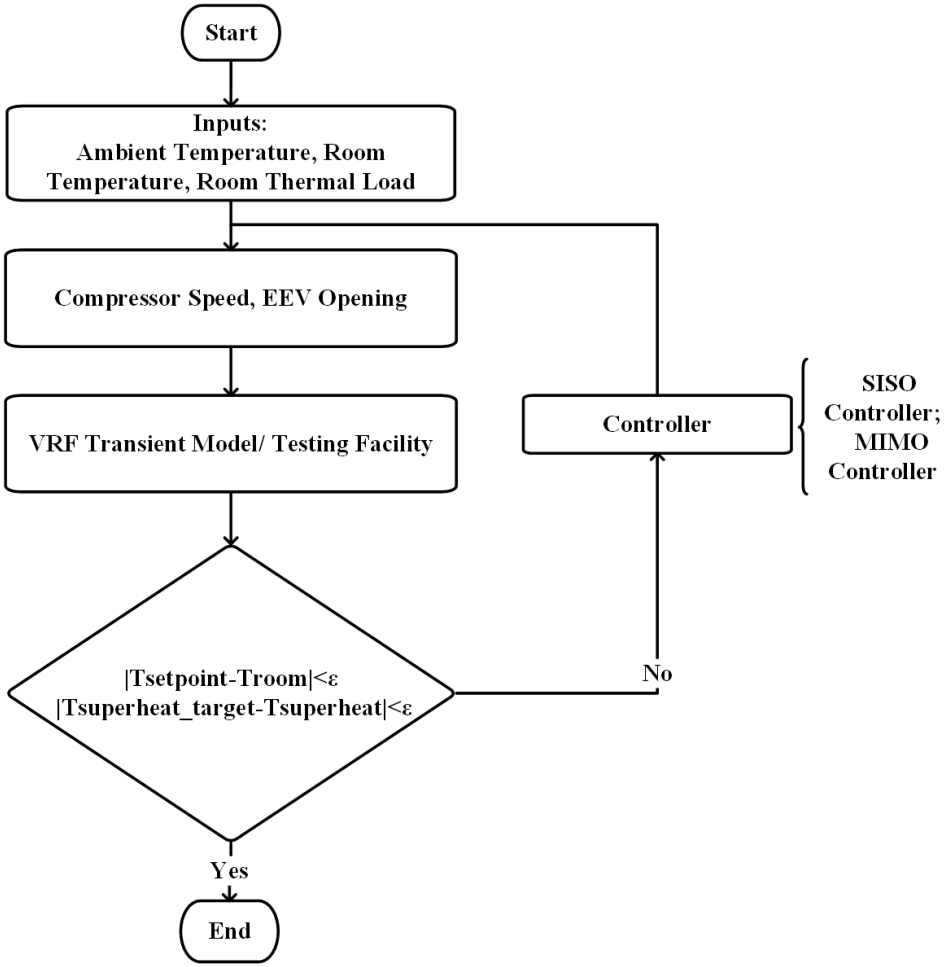
# IDVS Simulation Study




- **Simulation Approach**
  - **VRF delivered capacity and room load are calculated by EnergyPlus engine.**
  - **SDHP capacity is calculated by customized module:**
    - **The core is curve fitting generated from product data.**
    - **It uses RA OA information as inputs and outputs SDHP capacity.**
  - **Part load ratio of SDHP is the prime driving force of simulation.**

- **Highlights:**
  - **System is effective when room SHF is higher than 0.5.**
  - **IDVS saves 18.8% energy annually when compared to VRF-HRV system.**

# VRF Control Study




- Current VRF control studies focus:
  - Room temperature control
  - Superheat control
- Control variables:
  - Compressor speed
  - EEV steps

# Summary

- **Split System**
  - Category #1 uses additional components and water loop.
  - Category #2 uses effective temperature to represent thermal comfort.
  - Category #3 uses SHF to match with room load.
  - Category #1 is not compact.
  - Category #2 needs real-time measurement and a specific controller based on experience.
  - Category #3 has a lagging response and is applicable in a narrow range.

- **IDVS System**
  - Temperature and humidity control feature comes from SDHP, not VRF system.
  - Energy saving of VRF part comes from increased evaporating temperature.
  - Load of room is covered by both SDHP and VRF.
  - Operation of SDHP could increase the energy consumption.
  - IDVS improves ventilation.
  - IDVS increases total energy consumption.
  - IDVS increases VRF evaporating temperature.

# Future Research Suggestions

- **Apply the split system temperature and humidity control concept to VRF system.**
- **Apply split system temperature and humidity control concept to VRF:**
  - **Transient model needs to have a dedicated room model considering moisture balance and thermal comfort.**
  - **The controller architecture needs to include multiple variables.**
  - **The controller needs to be able to work under wider part load operation, ON/OFF operation→ wider range.**

# Acknowledgement

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