Under-Floor Air Distribution System (UFAD): Energy and Thermal Comfort Analysis

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Outline

• Introduction
• Motivation
• HVAC’s Air Distribution System Types
• Case Study
• Conclusion
Introduction

• Buildings are the biggest single energy consumption contributor.
• HVAC is consuming ~90% of a building energy in extreme hot weather such the Sate of Kuwait.
• Distribution systems claim to consume ~50% of the total HVAC consumption.
Introduction

Consideration when designing buildings
Motivations

• Selecting an efficient distribution system will contribute to saving substantially on energy consumption in a building.

• Also, improving the indoor air temperature and air mixing will lead to a better thermal comfort.

• Therefore, an efficient HVAC’s distribution system ensures the building sustainability since these elements are influential on the building energy consumption along its lifespan.
HVAC Distribution Systems Types

• Constant Air Volume (CAV)  
  - Most Common
• Variable Air Volume (VAV)  
  - More Efficient
• Displacement Ventilation (DV)  
• Under-floor Air Distribution (UFAD)  
• Variable Refrigerant Flow (VRF)  
  - Need Verification?
• Chilled Beam (CHB)
CAV and VAV

Figure 1
Schematic Diagram of a Typical Constant Air Volume (CAV) System
CAV and VAV

Figure 2
Schematic diagram of a typical Variable Air Volume (VAV) system

- Outside Air
- Filter
- Preheat Coil
- Variable Speed Supply Fan
- Cooling Coil
- Supply Air ~55°F
- Return Air ~75°F
- Variable Speed Return Fan
- ZONE A
- ZONE B
- ZONE C
- VAV Box A
- VAV Box B
- VAV Box C
- Building Boundary
DV, Chilled Beam and VRF
Main Concept of UFAD?

- The air is supplied through a raised floor to the occupants' area.
- This saves energy by conditioning only the air in the occupants’ zone.
- The ceiling based distribution supplies the air and returns it from the ceiling.
- So the total air volume is conditioned.
Main Concept of UFAD

Buildings Utilizing UFAD Systems

- Central Bank of Kuwait
- PAEET
- Kuwait Airport
- Kuwait Investment Authority
- Kuwait Criminal Bureau of Investigation
- Kuwait State Audit Bureau
Energy Use Index

Building Consumptions Vs. Local Benchmarking

<table>
<thead>
<tr>
<th>Actual Building Energy Consumption (kWh/m².year)</th>
<th>Typical Building Energy Consumption (kWh/m².year)</th>
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<tbody>
<tr>
<td>2008 599</td>
<td>2008 207</td>
</tr>
<tr>
<td>2009 622</td>
<td>2009 229</td>
</tr>
</tbody>
</table>

College of Technological Studies, Building 23 (7020 m²)

Kuwait State Audit Bureau (48,000 m²)
Main Benefit of UFAD System

• Energy savings of 25% compared with VAV systems (source: Building Simulation)

• Low-pressure plenum, usually 5-15 Pa, reduces the fan power and noise.

• Cut construction time by 15-25% (source: BAA Lynton)

• Improved thermal comfort

• Improved ventilation efficiency and indoor air quality

• Improved productivity and health.
Main Benefits of UFAD ... continued

- No draught
- Flexibility
- Personal control
- Easier to access and clean ductwork
- Get more points in the LEED scale
Typical Flexible Office layout
Typical Flexible Office layout
Difficulty of Implementing UFAD

• Lack of information and design guidelines
• Gaps in fundamental understanding
  • Room air stratification
  • Underfloor air supply plenum
  • Whole-building performance
• Perceived higher costs
• Limited application in retrofit construction
• Problems with applicable standards and codes.
Analyzing Energy and Thermal Comfort - Case Study

• Kuwait Audit Bureau is using UFAD, so a room within the building was selected as a test room

• Data loggers with four temperature sensors were installed

• Two locations were selected to install the data loggers (more than 1 m away from the supplied air)

• Sensors are allocated along the zone height elevation
Stratification

Fig. 4. Air temperature distribution at different heights on different times in 21st July at location 1.

Fig. 5. Air temperature distribution at different heights on different times in 21st July at location 2.
# Energy Analysis

<table>
<thead>
<tr>
<th></th>
<th>Supply air temperature 18°C &amp;</th>
<th>Thermostat Set 24°C</th>
<th>Thermostat Set 26°C</th>
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<tbody>
<tr>
<td></td>
<td>Cooling Coil (W)</td>
<td>Fan Energy (W)</td>
<td>Total</td>
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<tr>
<td>July</td>
<td>514894</td>
<td>19126</td>
<td>534020</td>
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<tr>
<td>August</td>
<td>548694</td>
<td>25950</td>
<td>574643</td>
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<td>Sept.</td>
<td>483578</td>
<td>25713</td>
<td>509291</td>
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</table>

Supply air temperature 18°C & Thermostat Set 24°C

Supply air temperature 18°C & Thermostat Set 26°C
Energy Analysis

![Graph showing energy consumption for July and August. The graph compares Total Energy Consumption: Cooling, Coil, and Fan (W) across different types of systems, including CBAD_VAVType, Actual UFAD, UFAD_SAT18_STAT24, and UFAD_SAT20_STAT24.]
Thermal Comfort Analysis
Occupants Questionnaire

Percentage of people responses with respect to thermal sensation scale

- Slightly warm, warm & hot: 0%
- Neutral: 20%
- Slightly cool: 27.5%
- Cool: 30%
- Cold: 22.5%
CFD Analysis

[18°C supply temp. and 1.5 m/s velocity]

[21°C supply temp. and 1.0 m/s velocity]
Conclusions

1. UFAD cans save more than 25% of energy, in the tested room, at supply temperature 21°C.

2. Best air stratification achieved at 1 m/s of supply air velocity.

3. The above supply condition proved that thermal comfort and air distribution are improved.

4. The UFAD System was operated incorrectly, so to insure the above benefits, the operators need to be trained and closely managed.
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