ESL-IC-14-09-04a

Research and Application of RCF Technology in Public Buildings

RCF, Stands for "Radiant Ceiling plus Fresh Air"

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Proceedings of the 14th International Conference for Enhanced Building Operations, Beijing, China, September 14-17, 2014

Research and Application of RCF Technology in Public Buildings

Author's Background

Mr. Jiguang Yan

* Bachelor of Science
* Senior HVACR Engineer
* RCF Patent Holder
* Deputy Chief of Refrigeration and Air Conditioning Engineer Committee

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* Bachelor of Science, Master of Science
* State Charted Engineer
* Member of ASHRAE

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Research and Application of RCF Technology in Public Buildings

Research and Application of RCF Technology in Public Buildings

1. BACKGROUND

1.1 Application Fact

- RCF, with radiant panel installed & fresh air supplied
- Verified 40% energy saving
- Proved 90% maintenance cost reduction
- Solving problem of condensation & low radiant intensity of the European tech
- Based on over 14-year research & 8-year empirical applications
- Assessed on the thermal test for various envelope structures, seasons and different space functions
- Patent in China Mainland, Hong Kong, Singapore, Australia
- Patent in progress for Europe, the USA
- RCF contribution to HVACR field cause a lot of skepticism

1.2 Author's Viewpoint

- The radiant heat transfer is the ground of the RCF technology
- Existing computing method for the convective air conditioning no longer appropriate to the RCF
- RCF's thermal figures should be obtained through experimentation
- Thermal radiation replaces thermal convection for more comfortable space cooling

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2. THE MICRO-MECHANISM OF HEAT TRANSFER

2.1 Thermal Conduction, Convection & Fourier's Theorem

- $q = -\lambda \, \text{grad} \, t$ W/㎡
- Heat flux, proportional to the temperature gradient
- λ derived from large amount of experimentation
- "-" sign indicates the opposite direction of the temperature gradient and heat flow
- Foundation for the AIR conditioning

(Ref: Zhang Ximin and Ren Ze, 1993)

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2. THE MICRO-MECHANISM OF HEAT TRANSFER

2.2 Thermal Radiation& Stephen-Boltzmann's Law

- Stephen-Boltzmann's Law $$Q_{12} = C_{12}\Phi_{12}F_1\left[\left(\frac{T_1}{100}\right)^4-\left(\frac{T_2}{100}\right)^4\right] \quad W/m^2$$
- Features of thermal radiation
  - Related to Colour, View Factor, T of the surfaces
  - The 4^{th} power to the surface temperature of T
  - Happen between any objects (T> 0 ˚K)
  - Have strong direction (object – object)
  - By electromagnetic waves/particles
  - Accompanied with twice energy exchange
    - Heat power firstly converts to electromagnetic waves which reach the object
    - The waves are absorbed by the object through the changed style of heat energy

    (Ultimately demonstrate by the variation of the object's T)
  - The waves can travel in a vacuum (AIR unnecessary as a medium)
  - Transfer rapidly (speed of light)
- RCF tech based on Stephen-Boltzmann's Law

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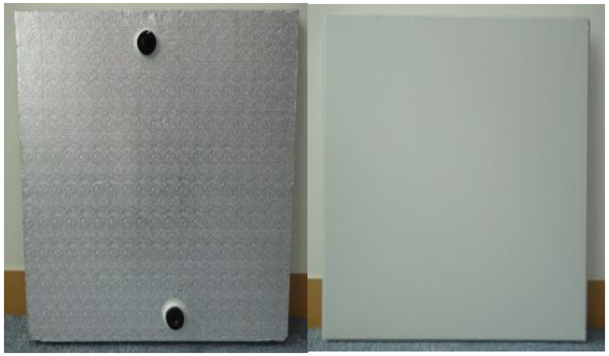
3. THERMAL ANALYSIS OF THE RCF TECHNOLOGY
3.1 RCF Application Background

	
RCF Patent Panel (standard)	RCF Patent PAU

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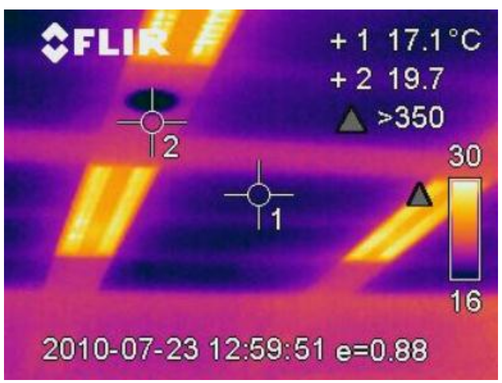
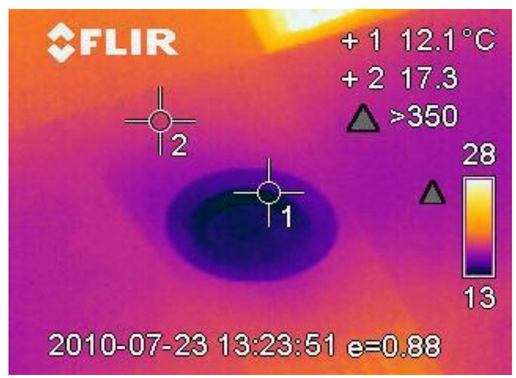
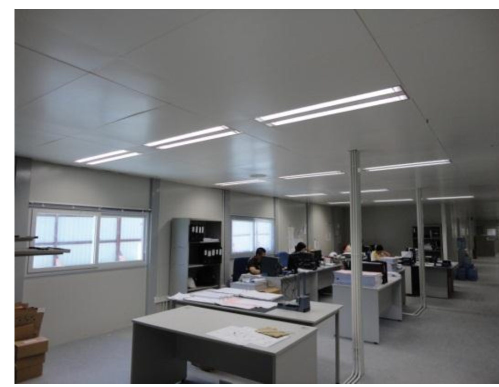
3. THERMAL ANALYSIS OF THE RCF TECHNOLOGY

3.1 RCF Application Background

- The client, Cathy Pacific Services Limited
- AEM, Active Energy Management, British, to evaluate this RCF system
- Three consecutive days testing, in July, 2010







RCF Operative Photo, July 23, 2010, Image Courtesy of AEM

(Ref: Phil Healey, et, 2010)

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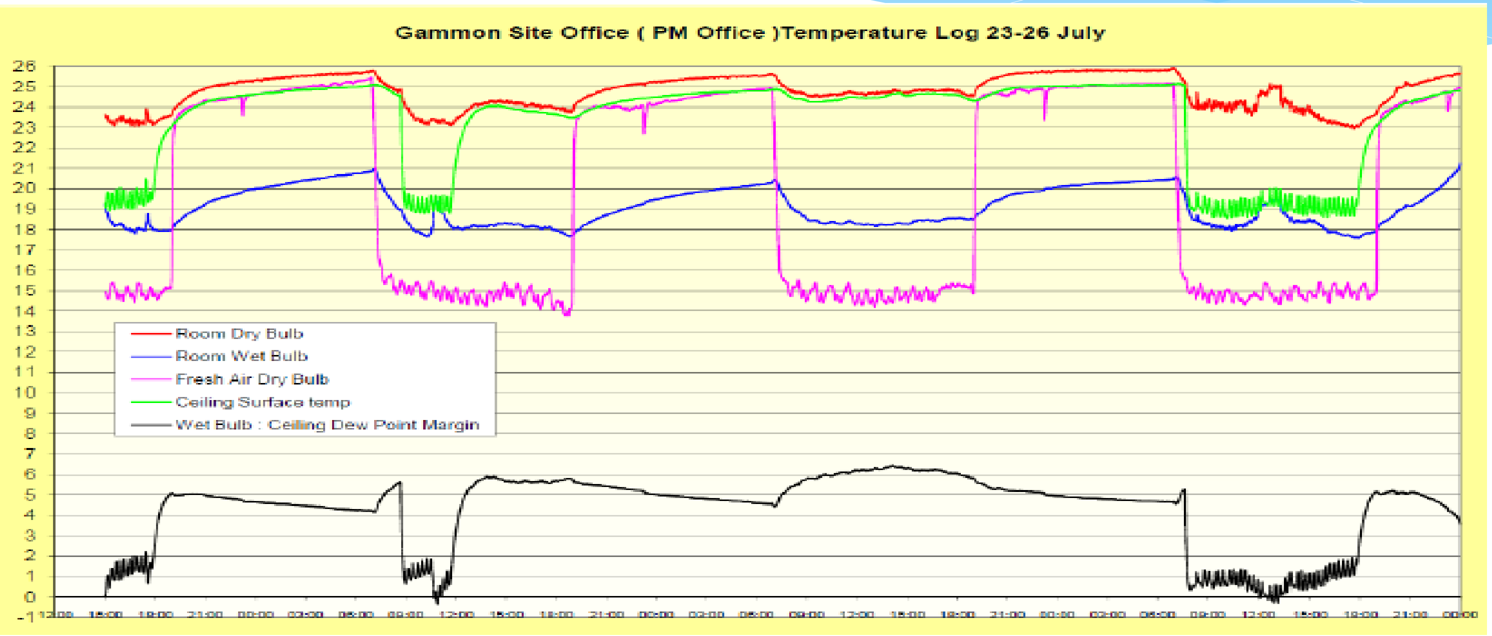
3. THERMAL ANALYSIS OF THE RCF TECHNOLOGY

3.2 RCF Testing Data



- Excellent IAQ
- Even T distribution
- Intelligent control
- ± 0.5 °C T fluctuation
- Remote monitoring and operating

(Ref: Phil Healey, et, 2010)

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3. THERMAL ANALYSIS OF THE RCF

3.3 RCF Testing Result/Report

- Higher indoor comfort level compared to the traditional air conditioning
- No condensation, in Hong Kong, a humid region, in the hottest and wettest season
- Indoor data: T_{DB}=23˚C, RH = 60%, T_P = 17.1˚C and T_{WI} = 21˚C
- Outdoor data: T_{DB} = 33.4˚C
- Key Finding: T_{WI} = 21˚C < T_{AI} = 23˚C, i.e. T_{WI} distribution with RCF system, unlike the T_{WI} used traditional air conditioning

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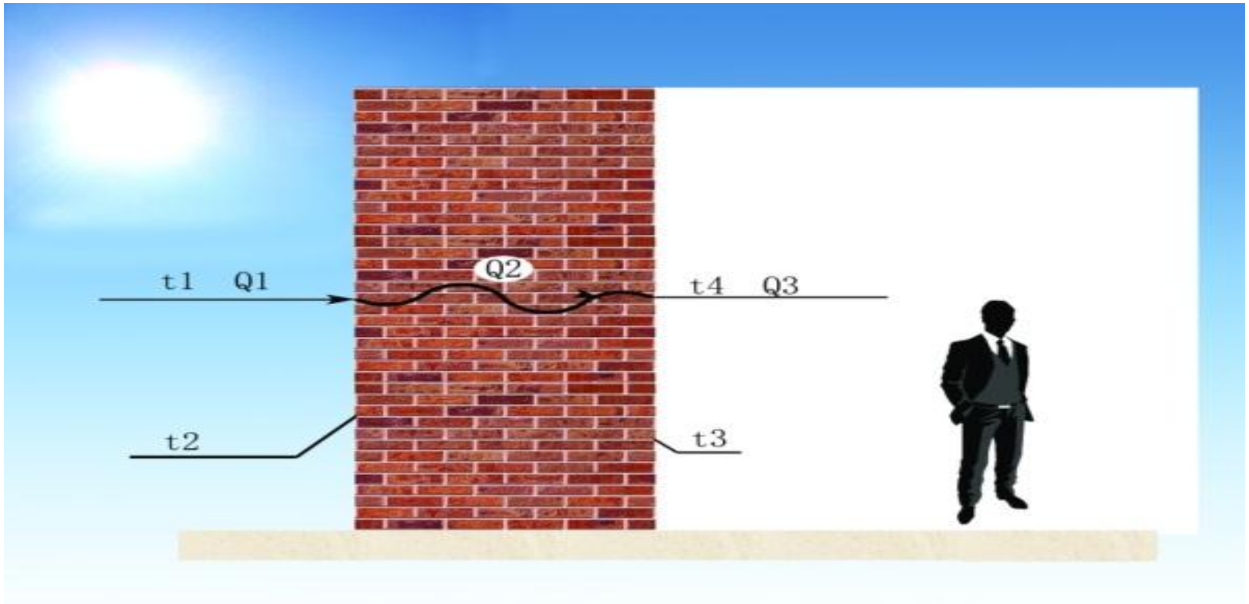
3. THERMAL ANALYSIS OF THE RCF APPLICATION

3.4 Thermal Calculation Based on Conventional Thermal Theory

- In line with the traditional air-conditioning thermal model
- Based on the continuity characteristics of mathematical equation
  - Have $Q_1 = Q_2 = Q_3$ as known by the Fourier's Law
  - The prerequisite of $t_1 > t_2 > t_3 > t_4$ has to be satisfied, but it hasn't (see section 3.5)



Schematic of Convective Heat Transfer

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3 THERMAL ANALYSIS OF THE RCF APPLICATION

3.5 Thermal Calculation According to Thermal Radiation Model

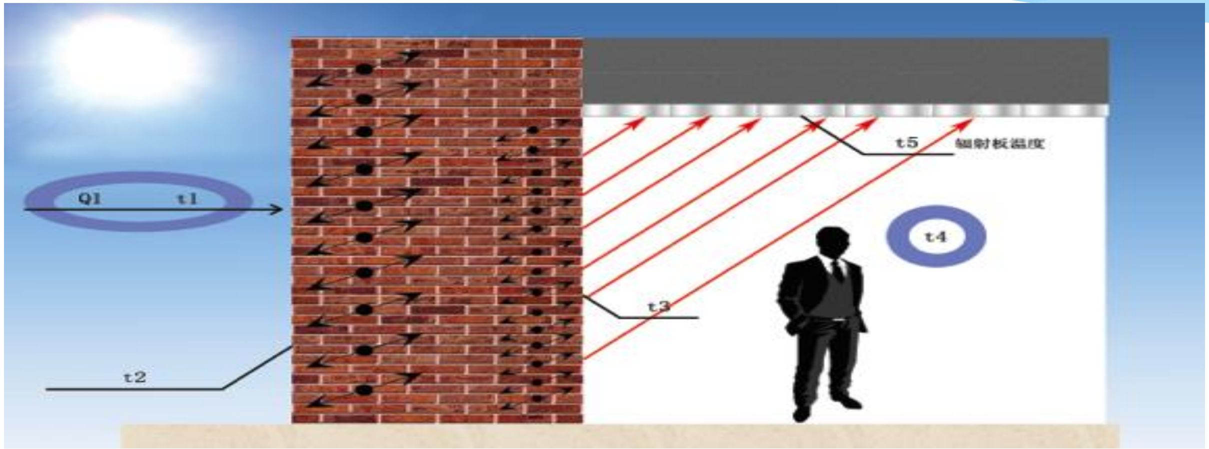

Diagram of Radiant Heat Transfer (Derived from the above infrared photo)

- Scenario of the RCF System
  - Temperature pattern: $t_1 > t_2 > t_3 < t_4$ due to the direct radiation between surfaces
  - t_3 of the interior wall surface, affected by both the cool panels inside via thermal radiation & the outside hot wall surface through thermal conduction
  - $t_3 < t_4$, when $Q_{WI-P} > Q_2$
  - $t_3 < t_4$ as a result of the air is "transparent" in the thermal radiation process

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3. THERMAL ANALYSIS OF THE RCF APPLICATION

3.6 Heat Transfer Investigation through Walls in Thermal Radiation Model

- Based on the traditional air-conditioning theory
  - $Q_{RCF} > Q_{AC}$ because the t_3 of the RCF < t_3' of the traditional air-conditioning
  - **QUESTIONING** how the RCF system can save more energy

- Based on the micro heat transfer & thermal radiation
  - The molecule in the wall structure vibrating & T_W raised up & the molecule kinetic energy rise
  - This kinetic energy transmits to the inside wall with macro-performance of the elevated interior wall surface temperature T_{WI}
  - Simultaneously the molecule near the interior surface of the wall get the cold radiation from the chilled panel with constant momentum lose
  - Consequently $t_3 < t_4$, when $Q_{WI\text{-}P} > Q_2$
  - Due to $t_3 < t_4$, Consequently $Q_{WI\text{-}P}$ could be more and more close to 0, Q_1 & Q_2 would be to zero too which inconsistent with the energy conservation rule

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3. THERMAL ANALYSIS OF THE RCF APPLICATION
3.7 The Author's Inference

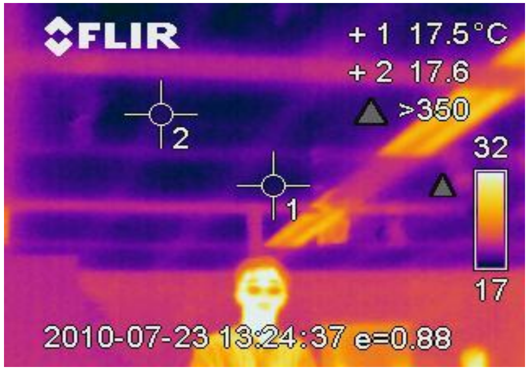
- $t_3 = t_4$ or $t_3 < t_4$ working conditions exist in the RCF system
- Dissimilar thermal scenarios between RCF & traditional air conditioning
- The thermal calculation model for the traditional air-conditioning, no longer suitable to the RCF system
- The efficiency of panels' heat exchange
  - Depends on radiant panels' structure, configuration
  - Vary for different products
  - Should be gained through experimentation
  - The specified testing parameter achieved for one pattern of panel can only be proper to this type of panel itself

Research and Application of RCF Technology in Public Buildings

4. HUMAN COMFORT LEVEL AND RCF SYSTEM LOAD STUDY

4.1 Thermal Comfort Analysis in a RCF Room

- Human Thermal Comfort
  - Head temperature 32˚C
  - Clothing surface 28˚C
  - All surfaces T ≤ person's body T
  - ΔT of human head and radiation ceiling,14.5˚C
  - 10.5˚C distinction for the human clothing and ceilings
  - The occupant in an environment with strong radiative heat transition & powerful cold feeling



Inferred Images of Human and Enclosures with RCF

Image Courtesy of AEM

(Ref: Phil Healey et, 2010)

Research and Application of RCF Technology in Public Buildings

4. HUMAN COMFORT LEVEL AND RCF SYSTEM LOAD STUDY

4.1 Thermal Comfort Analysis in a RCF Room

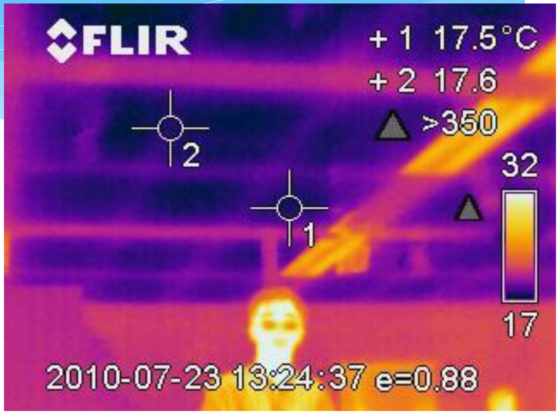
- Enclosures load
  - All inner surface & ceilings with about ΔT of 5˚C (22.5˚C, 17.5˚C)
  - Q of all interior surface to the radiant panel relatively very low compared to AIR conditioning

(Ref: Phil Healey et, 2010)

Research and Application of RCF Technology in Public Buildings

4. HUMAN COMFORT LEVEL AND RCF SYSTEM LOAD STUDY

4.1 Thermal Comfort Analysis in a RCF Room



- RCF Performance
  - Identical results from RCF application reasoning and computing evaluation to the chilled water side
  - Extremely pleased by the young adult to set panels' surface control temperature at 20˚C
  - Characteristics of tracing the heat source of human which only has a few load to the RCF panel
  - The lamp with the view factor of 0 to the chilled ceiling which consequently cause almost zero load to the RCF system despite it has larger heat load
  - Much lower energy consumption for the same comfort
  - Site subjective assessment on the PMV and PPD satisfied with the ASHRAE standard

(Ref: Phil Healey et, 2010)
(Ref: Sam. C. M. Hui et, 2012)

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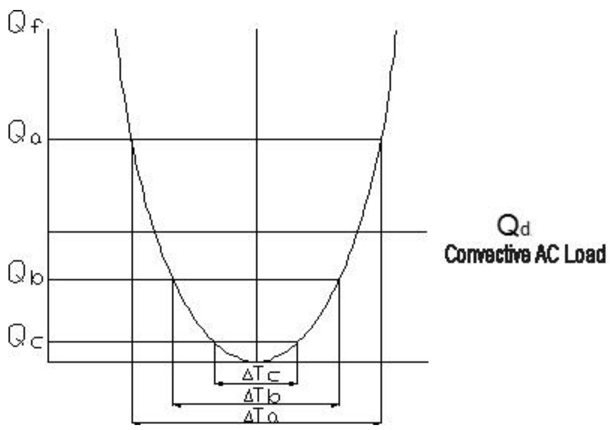
4. HUMAN COMFORT LEVEL AND RCF SYSTEM LOAD STUDY

4.2 RCF Start-up and Running Load



RCF System Start-up and Running Load Curve

- "a" start-up moment
  - T_P = 293T
  - Envelope surface T_S = 301 with ⊿T = 8T
  - Ceiling load Q_a
- "b" state, about 20mins after start-up
  - T_P = 293T
  - Envelope surface T_S = 298 with ⊿T = 5T
  - Ceiling load Q_b
- "c" state, following a longer time running
  - Envelope surface T_S closer to the T_P
  - Radiative load decrease to Q_c

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4. HUMAN COMFORT LEVEL AND RCF SYSTEM LOAD STUDY

4.3 Application Outcome

- “a” startup stage with the maximum load
- “c” status, typical operative phase with extremely low load
- T_P of ceiling surface can be stabilized at a certain level
- The enclosure surface T should progressively approach to the T_P
- Consequently less and less running capacity would need for the RCF system
- The site subjective assessment on the PMV and PPD comply with ASHRAE Standard

(Ref: Sam. C. M. Hui et, 2012, Phil Healey, et, 2010)

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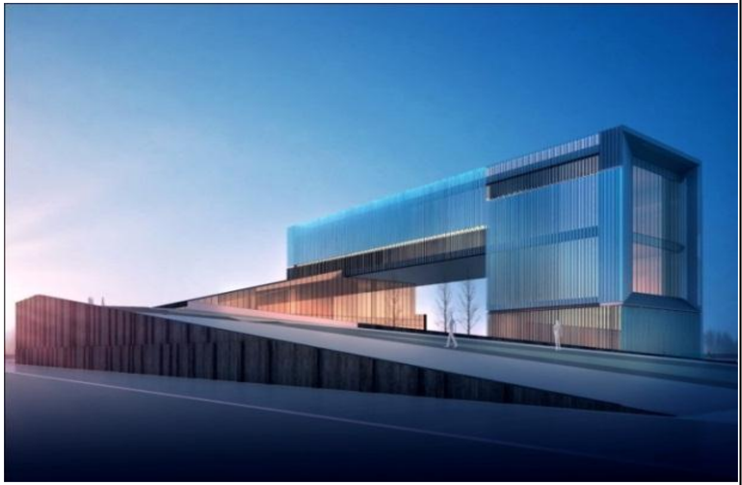
5. RCF APPLICATION IN JINWAN AVIATION EXHIBITION CENTER

5.1 Architectural Background

- Emblem building in Zhuhai
- Exhibit the City's planning & design on high-tech project and green low-carbon scheme
- Construction area of 6000 M^2 including 1600 M^2 office area
- Post-modernism architecture design

Front View



Back View

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5. RCF Application in Jinwan Aviation Exhibition Center
5.2 RCF Design Parameter

Comparison on Chiller Installation Index

RCF System	Traditional Convection System	Remark
75 w/m2	165 w/m2	RCF decreases 55% chiller installation capacity compared to original design

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5. RCF Application in Jinwan Aviation Exhibition Center
5.3 RCF Chillers Installed

Equipment	Specification, KW	Motor Power, KW	Unit	Qty.
Air-cooled Heat Pump	193.5	52.8	Pcs	2
Air-cooled Heat Pump	64.5	17.6	Pcs	1

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5. RCF Application in Jinwan Aviation Urban Planning Exhibition Center
5.4 RCF Indoor Operative Data and Photo

- Indoor operative data satisfies the standard of ASHRAE55-2010.

Panel Surface T	Wall Surface T	RH	CO_2 Content
17.5 ℃	22 ℃	58~65%	500~750 PPM

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5. RCF Application in Jinwan Aviation Exhibition Center

5.4 RCF Indoor Operative Data and Photo

Reception

Large Space Exhibition Hall

Multimedia Centre

Conference Room

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5. RCF Application in Jinwan Aviation Exhibition Center
5.5 RCF Application Contribution

- Principally difficult for it to achieve the goal of low-carbon green building
- RCF technology application makes this goal fulfilled
- Applying China Green Building Label

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6. CONCLUSION OF RCF APPLICATION

6.1 Purpose of the RCF Study

- Regulate human comfort level by thermal radiation
- Advance indoor air quality by deeply dehumidified fresh air and discharge of CO_2 without sacrifice human comfort
- Solving European tech problem
- Inspire more and more scholars/engineers to take part in thermal radiation research and development

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6. CONCLUSION OF RCF APPLICATION

6.2 European Similar Tech Analysis

- Started applying radiant ceiling for the space conditioning for several years
- Condensation problem, as a big obstacle, plagued its application for a long time
- Current solutions & consequence
  - Increase the chilled water temperature, along with the decreased radiant power
  - Set extra chilled beams as compensation to resolve the insufficient capacity with raised cost
  - Still the condensation problem cannot be solved
  - Bring about the dissatisfaction on the comfort requirement

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6. CONCLUSION OF RCF APPLICATION
6.3 Author's Point

- Energy expense hugely vary for different heat transfer methods
- RCF with distinct features of :-
  - Uniform panel surface temperature
  - Higher radiative intensity
  - Unique control logic
  - Verified at least 40% energy saving
  - Proved at least 50% maintenance cost reduction
  - Successfully used in many projects in Mainland and Hong Kong
  - Entirely solve the condensation problem in cold operation mode
- Cooling equipment start-up capacity and regulating ability for partial load is particularly vital
- Ceiling thermal radiation cannot be analyzed based on convective heat transfer & the plain fluid dynamics theory
- Suitable for office building, shopping mall, restaurant, airport, pharmaceutical factory, exhibition center and many other sites

(Ref: 2011~2012 Report, HEACO, Swire, HK)

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6. CONCLUSION OF RCF APPLICATION
6.4 RCF Extra Benefit

- Excellent IAQ
- Even T distribution
- Effective air treatment by super dehumidification capacity of PAU
- NO air draught feeling
- NO noise
- Save ceiling void at least 0.3M compared to VAV
- No need for setting chiller plant on the upper levels of the high-rise building
    - By using multi-stage heat exchanger for upper AC loading
    - Avoid the rotary load for the core and shell
    - Reduce core and shell construction cost dramatically
- Prevent cross-infection due to no air re-circulation
- Intelligent control
- Remote monitoring and operating

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AIRSTAR MISSION

Saving energy while improving quality of life
Building a better environment for future generations

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The End

Thanks

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Any Question?

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