ESL-IC-14-09-04

Research and Application of RCF Technology in Public Buildings

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

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Research and Application of RCF Technology in Public Buildings

Author's Background

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* BS
* Senior HVACR Engineer
* RCF Patent Holder
* Director of CAR
* Vice Chairman of RACEC

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* BS., MS.
* State Charted Engineer
* ASHRAE Member

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Research and Application of RCF Technology in Public Buildings

1. BACKGROUND
2. THE MICRO-MECHANISM OF HEAT TRANSFER
3. THERMAL ANALYSIS OF THE RCF TECHNOLOGY
4. HUMAN COMFORT LEVEL AND RCF SYSTEM LOAD STUDY
5. RCF APPLICATION IN JINWAN AVIATION EXHIBITION CENTER
6. CONCLUSION OF RCF APPLICATION
7. REFERENCES

Research and Application of RCF Technology in Public Buildings

1. BACKGROUND

1.1 Application Fact

- RCF, with radiant panel installed & fresh air supplied
- 40% energy saving verified
- 90% maintenance cost reduction proven

- Solved European product problem of condensation & low radiant intensity

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 achieved in China Mainland, Hong Kong, Singapore, Australia, Japan

Patent in progress for Europe, the USA

1.2 Author's Viewpoint

- The radiant heat transfer, **Stephen-Boltzmann's Law**, the foundation of the RCF
- 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 , achievable with less cost

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2. THE MICRO-MECHANISM OF HEAT TRANSFER

2.1 Thermal Conduction, Convection & Fourier's Theorem

$$Q = -\lambda \, \text{grad} \, t \quad W/m^2$$

- 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

$$Q_{12} = C_{12}\,\Phi_{12} F_1 \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right] \quad \text{W/m}^2$$

- Stephen-Boltzmann's Law

- Features of thermal radiation
  - Happens between any objects (T> 0 °K)
  - Has strong direction (b/t object – object)
  - Transfers by electromagnetic waves
  - Accompanied with twice energy exchange
    - Heat power firstly converts to electromagnetic waves which reach the object
    - The waves are then 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 (as the light speed)

- **RCF, based on Stephen-Boltzmann's Law**

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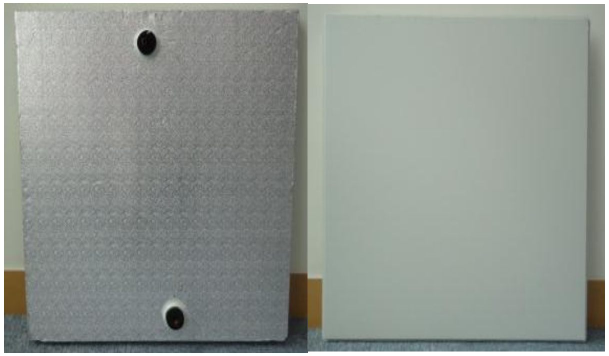
3. THERMAL ANALYSIS OF THE RCF TECHNOLOGY

3.1 RCF Application Background



RCF Patent Panel (standard)	RCF Patent PAU

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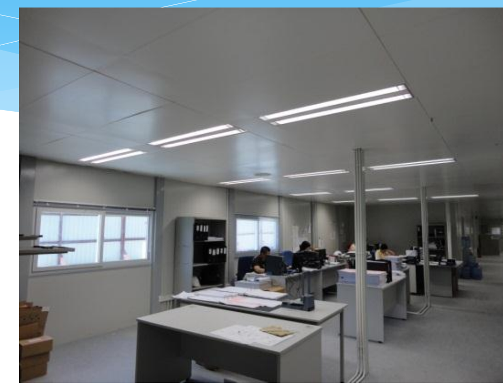
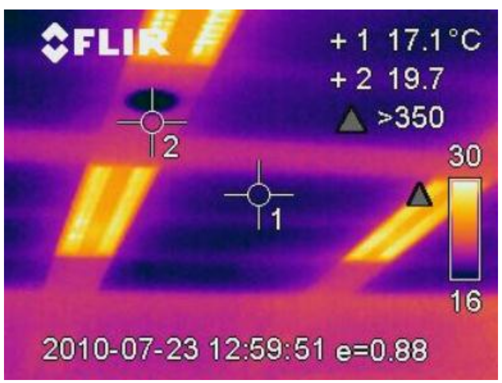
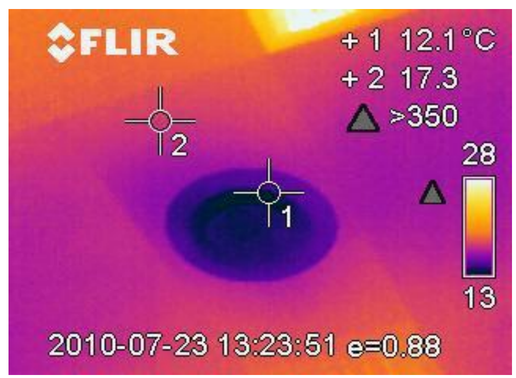
3. THERMAL ANALYSIS OF THE RCF TECHNOLOGY

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/recording, in July, 2010





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

(Ref: Phil Healey, et, 2010)

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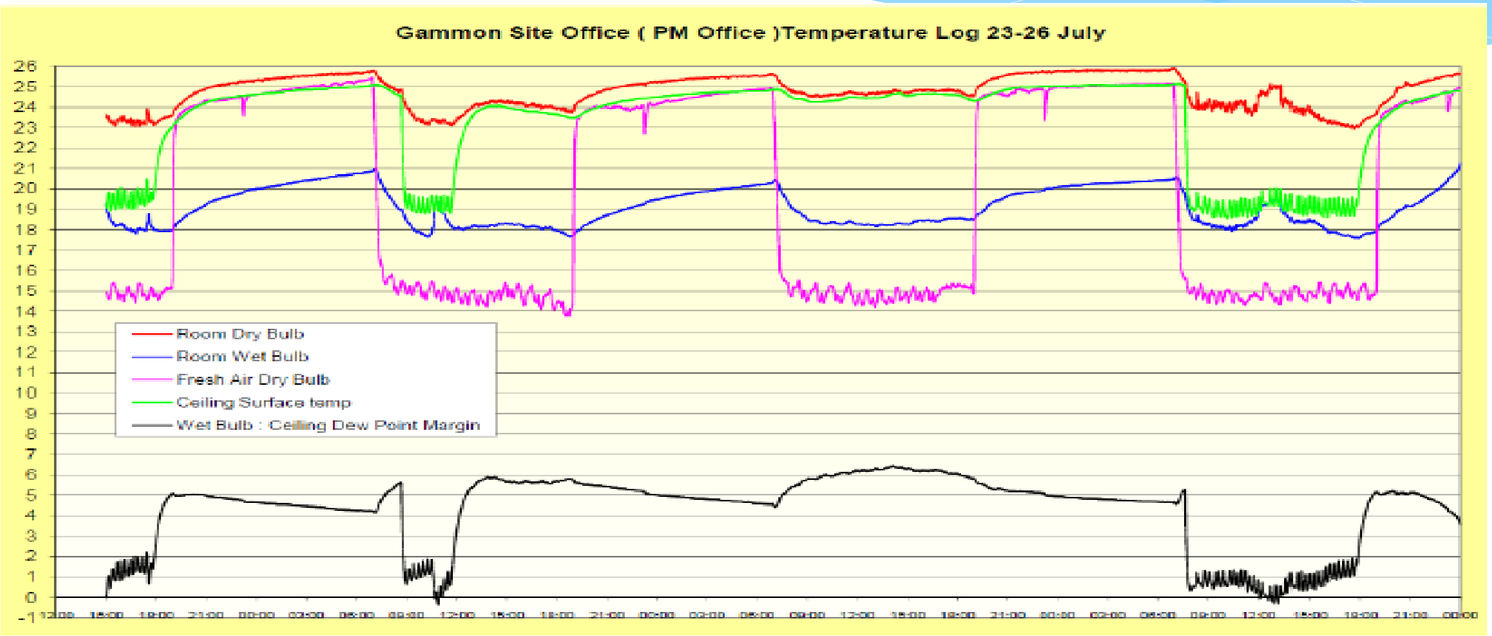
3. THERMAL ANALYSIS OF THE RCF TECHNOLOGY

3.2 RCF Testing Data



- Excellent IAQ
- Even T distribution
- Only ± 0.5 °C T fluctuation

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(Ref: Phil Healey, et, 2010)

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3. THERMAL ANALYSIS OF THE RCF

3.3 RCF Testing Report by AEM

- **Indoor data**: T_{DB}=23˚C, RH = 60%, $\mathbf{T_P}$ **= 17.1˚C** and $\mathbf{T_{WI}}$ **= 21˚C**

NO condensation, in Hong Kong, a humid region, in the hottest and wettest season

- **Key Finding**: T_{WI} = 21˚C < T_{AI} = 23~24˚C, i.e. $\mathbf{T_{WI}}$ **distribution with RCF** system, **unlike** the T_{WI} in the space used **traditional air conditioning**

- **Higher indoor comfort level,** compared to the traditional air conditioning

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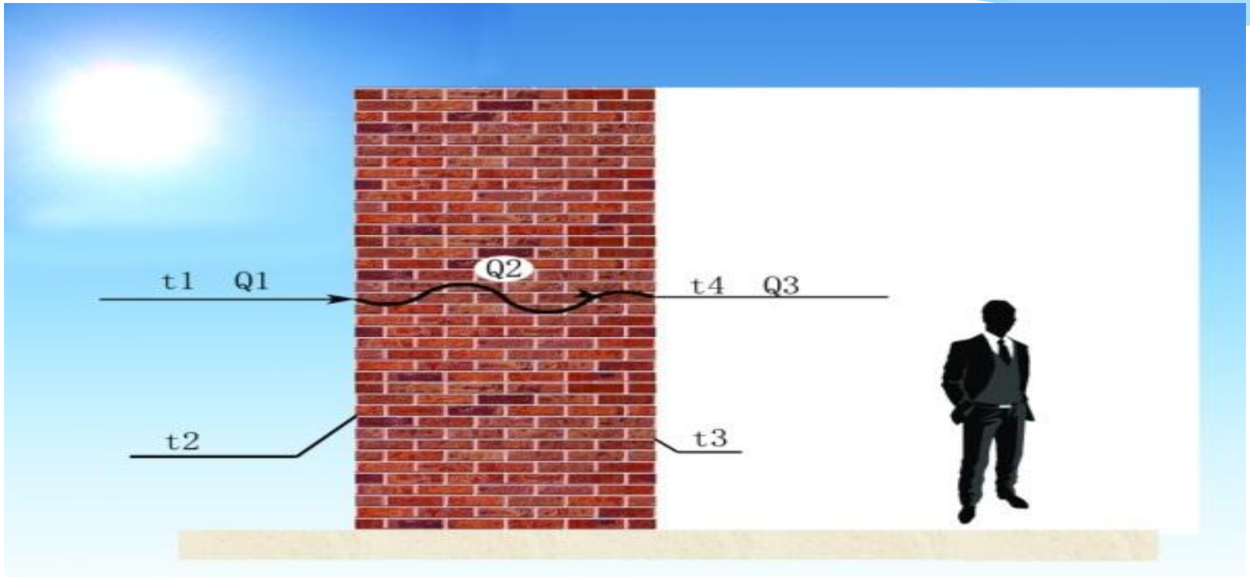
3. THERMAL ANALYSIS OF THE RCF APPLICATION

3.4 Thermal Calculation Based on Thermal Convention Theory



Schematic of Convective Heat Transfer

- In line with the traditional air-conditioning thermal model
- Based on the continuity characteristics of mathematical equation
  - Should 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

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3 THERMAL ANALYSIS OF THE RCF APPLICATION

3.5 Thermal Calculation According to Thermal Radiation Model

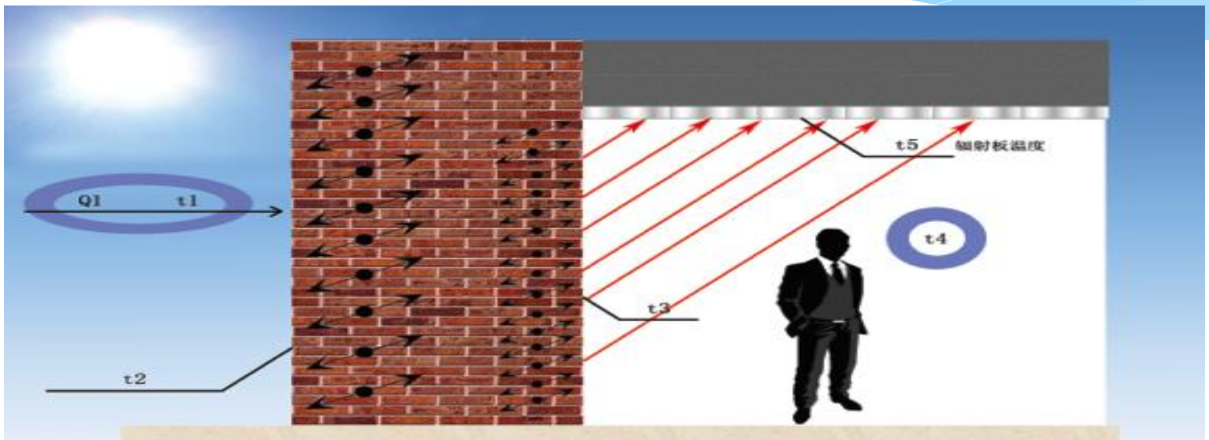

Diagram of Radiant Heat Transfer (Derived from the fore-mentioned infrared photo)

- **Space scenario with the RCF System applied**
  - Temperature pattern: $t_1 > t_2 > t_3$ **$< t_4$**
- **Why?** The **direct radiation** between surfaces exists:
  - $t_3 < t_4$, **when** $Q_{WI}\text{-}_P > Q_2$
- $t_3 < t_4$, also a result of the **AIR** is "transparent" in the thermal radiation process, **in line with the Stephen-Boltzman's law**

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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 $t_3 < t_4$ exists, $Q_{WI\text{-}P}$ could be more and more close to 0, Consequently Q_1 & Q_2 would be zero too

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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 from different manufacturers
  - Data should be gained through application model

- The specified testing parameter achieved for one pattern of panel can only be proper to this type of panel itself

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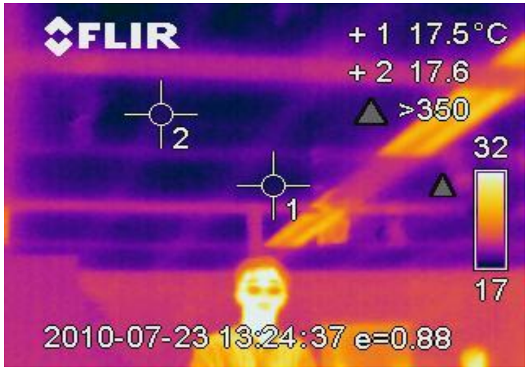
4. HUMAN COMFORT LEVEL AND RCF SYSTEM LOAD STUDY

4.1 Thermal Comfort Analysis in a RCF Room

- Human Thermal Comfort
  - Head T, 32 ˚C
  - Clothing surface T, 28 ˚C
  - All surfaces T ≤ person's body T
  - ΔT of human head and radiation ceiling,14.5 ˚C
  - 10.5 ˚C T distinction for the human clothing and ceilings



Infrared Image of Human and Enclosures with RCF System
Image Courtesy of AEM

- The occupant, in **an environment with strong radiative heat transition** & **powerful cold feeling**

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

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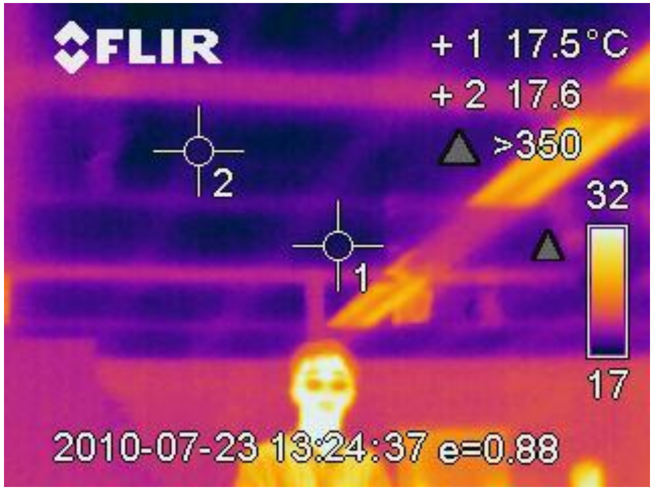
4. HUMAN COMFORT LEVEL AND RCF SYSTEM LOAD STUDY

4.1 Thermal Comfort Analysis in a RCF Room

- Enclosures
  - All inner surface with about ΔT of 5˚C with the cool ceilings (22.5˚C, 17.5˚C)

- RCF Performance Characteristics
  - Tracing the heat source of human which only has a few load to the RCF panel
  - T of **all interior surface** to the radiant panel, relatively very low compared to AIR conditioning (ΔT b/t indoor air and supplied air is larger than 5˚C)
  - Much lower energy consumption against AIR Conditioning for the same comfort level



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

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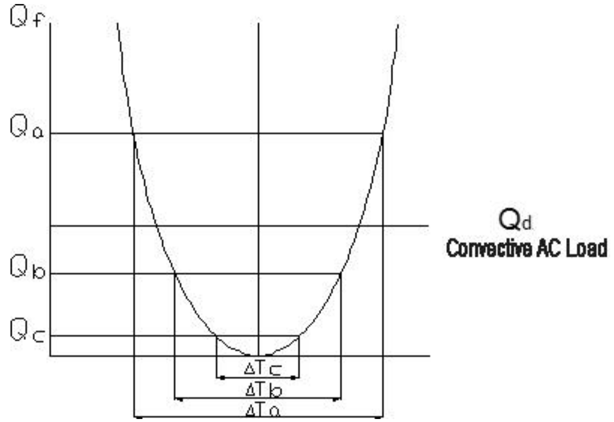
4. HUMAN COMFORT LEVEL AND RCF SYSTEM LOAD STUDY

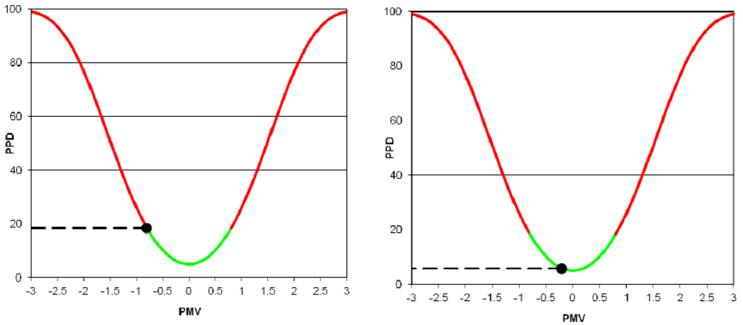
4.2 RCF Start-up and Running Load



RCF System Start-up and Running Load Curve

- "a" 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 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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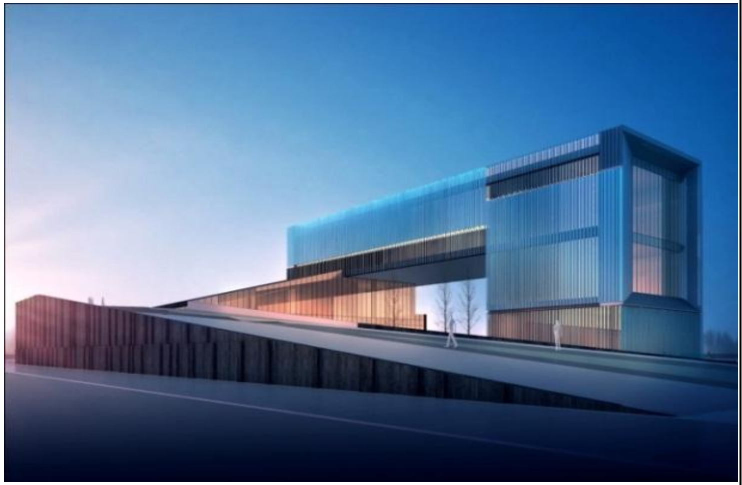
5. RCF APPLICATION IN JINWAN AVIATION EXHIBITION CENTER

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 6,000 M^2 including 1,600 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 Factor

RCF System Installed	VAV System Required
75 w/m2	165 w/m2

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

◆ **RCF decreases 55% chiller installation capacity compared to original design**

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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 RCF Study Outcome

- Better regulate human comfort level through the thermal radiation
- Advance indoor air quality by deeply dehumidified fresh air and discharge of CO_2 without sacrifice human comfort
- Solved European problem on this kind of product application
- Inspire more and more scholars/engineers to take part in thermal radiation research and development, such as HKU, AEM, HKIE, CIBSE and so on

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6. CONCLUSION OF RCF APPLICATION

6.3 Author's Viewpoints

- Energy expense hugely vary for different heat transfer methods
- Cooling equipment start-up capacity and regulating ability for partial load are particularly vital
- Ceiling thermal radiation cannot be analyzed based on convective heat transfer
- 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 Conclusion

- RCF with Distinct Features of :-
  - Uniform panel surface temperature
  - Higher radiative intensity
  - Effective air treatment by PAU with super dehumidification capacity
  - Unique & Intelligent control logic
  - Entirely solve the condensation problem in cold operation mode
  - Remote monitoring and operating
- RCF Main Benefits to the Clients/Society:-
  - Excellent IAQ
  - At least 40% energy saving
  - At least 50% maintenance cost reduction
  - NO air draught feeling
  - NO noise
  - Save ceiling void at least 0.3M compared to VAV
  - No need for setting chiller plant rooms on the upper level of the high-rise building
  - Prevent cross-infection due to no air re-circulation
  - Successfully used in many projects in Mainland, Hong Kong

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AIRSTAR MISSION

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

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Thanks

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