亚太低碳技术高峰论坛
Asia pacific summit on Low Carbon Technology

冬冷高湿地区辐射空调供暖
—以空气载能辐射空调系统为例

Radiant Heating System in Cold-winter and High-humidity Area
—Research on Air Carrying Energy Radiant System (ACERS)

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冬冷高湿地区的气候特征，例如长沙地区：
Climate in cold winter and high humidity area, like Changsha:

- 全年高湿，冬季相对湿度高达90%。
  High humidity (over 90%)
- 冬季日平均最低气温低于6ºC的天数为90天左右。
  The number of days, when $Ta < 6$ºC, is more than 90 in winter.
- 冬季非供暖条件下，室内绝大部分时间温度过低(7ºC左右)，人体热舒适性差。
  When there is no heating in winter, the indoor temperature is very low (about 7ºC), and people often feel uncomfortable.

目前主要的供暖方式如下：

The current main heating terminals are as follows：

安装简单，价格便宜，
但**温度**分布**不均匀**，还会有**吹风感**，**高噪音**。

成本低、使用方便，
但存在**环境污染**和**安全**问题。

The convection heating systems and electric heating equipment are cheap, but they still have some problems：

- Uneven temperature distribution
- Environmental pollution
- High noise
- Risk of security
- Draft sensation
- ……

相对对流式供暖末端而言，辐射供暖末端既**舒适**又**节能**，是解决冬冷高湿地区供暖问题的有效途径。

Comparing to the convection terminal, the radiant terminal is **comfortable** and **energy-saving**. It is an effective way to solve the heating problem in cold winter and high humidity area.

毛细管式辐射板 Capillary radiant system

电热板 Radiant heating plate

然而以液体为载能介质的毛细管辐射系统和电辐射系统的投资成本高、后期维护困难，同时在夏热冬冷地区较难实现空调末端冬夏一体化。因此课题组开展了以空气为载能介质的**低成本**的新型**辐射末端**研究。

However, the current radiant systems still have the following problems:

- Difficulties in later maintenance
- High installation and cost of the radiant systems
- Hard to integration of air conditioning in winter and summer

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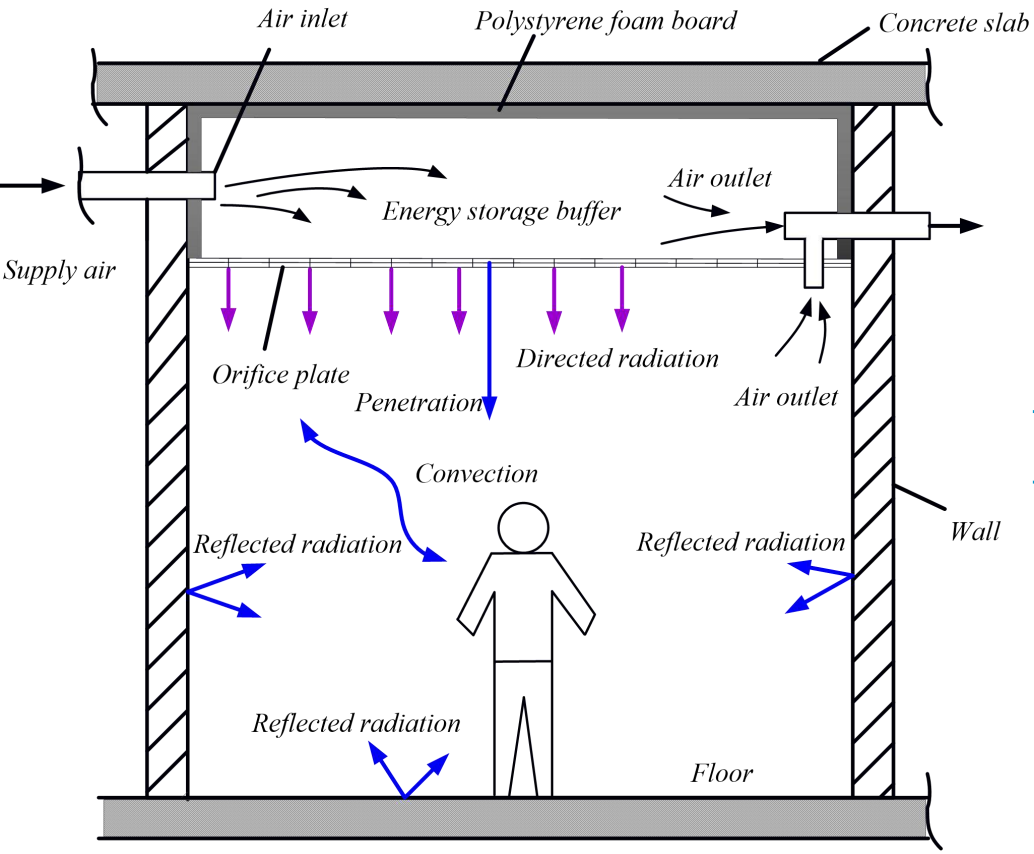
Therefore, our research group has carried out the research on the novel radiant terminal using air as the energy-carrying medium, and proposed the air carrying energy radiant system (ACERS).

空气载能辐射空调系统
The terminal of ACERS

空气载能辐射末端以空气为传热介质，以孔板为辐射末端，整个系统设计简单，安装灵活，易于施工和维护。

- The terminal of the ACERS is the metal orifice plate, and the heat transfer medium of ACERS is air.
- The ACERS is **flexible** in installation, **low** cost and **easy** for maintenance.



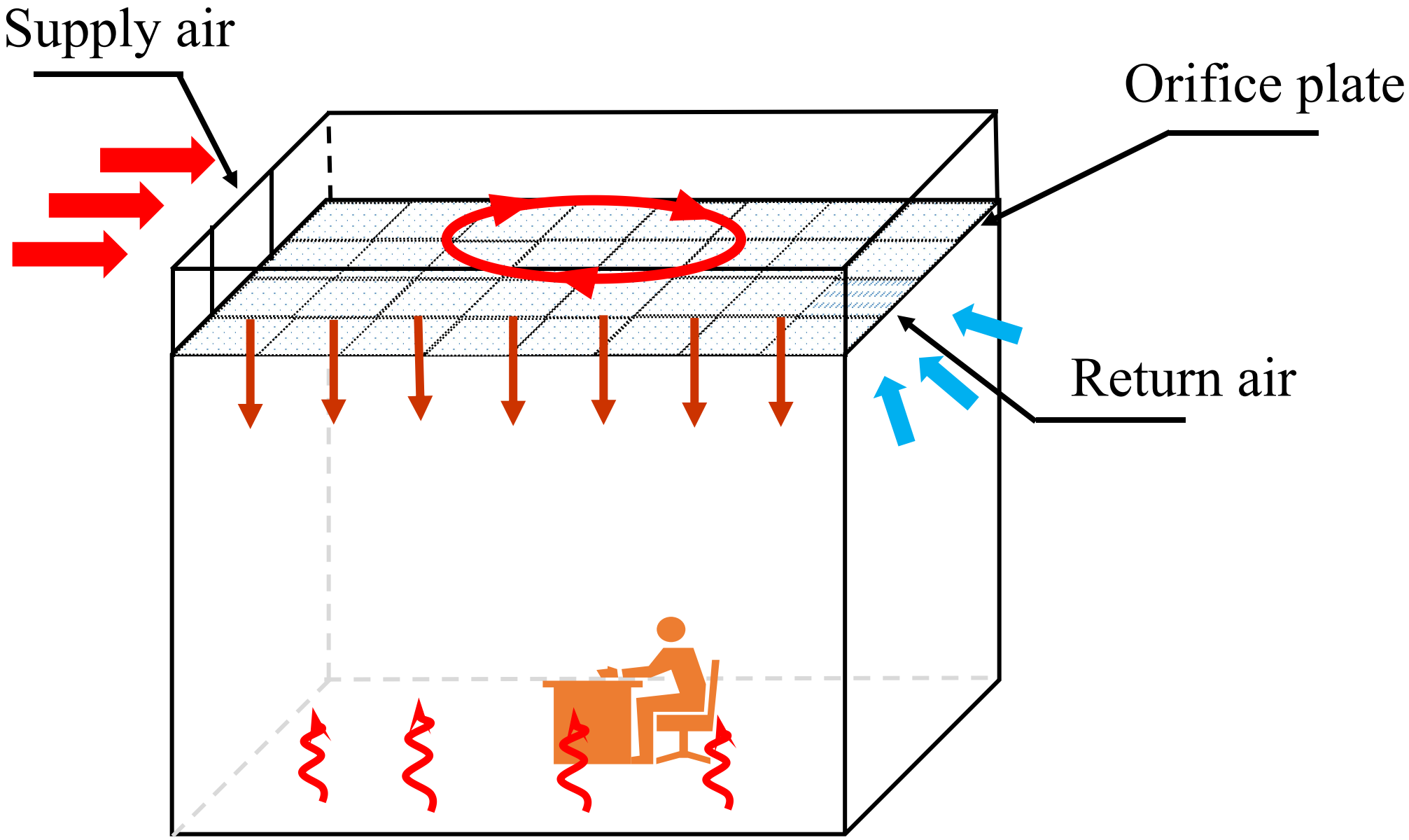
空气载能辐射系统原理图

Principle diagram of ACERS

1、空调冷、暖空气不直接送入下部空调区，而是送入上部缓冲蓄能区，在缓冲蓄能区，大部分空气以对流换热方式将冷、热能传递给金属天花板后直接返回空调机。

2、小部分空气经金属天花板上的微孔渗透至空调区，消除余湿后经回风口返回空调机，金属天花板则不断从循环空气中获取冷、热能，逐渐加大与空调区的温差， 并以辐射换热的方式对空调区进行空调，如此循环运行，实现由循环空气载能的天花板辐射换热空调。

Firstly, the cooling/heating air is sent to the energy storage buffer zone for energy exchange and stabilizing pressure. **After** transferring heat with the orifice plates, most of air flows out via air return outlet and the rest of air enters into the room through micro pores. **Then,** the air penetrated through the orifice can form an air layer near the ceiling plates that reduces the condensation risk in summer. **Finally** this part of air flows out through the air return outlet in air-conditioning zone.


Supply air
Orifice plate
Return air

2 空气载能辐射系统原理与特性 Principle and characteristic of ACERS

2.1 空气载能辐射空调负荷计算方法 Load calculation of ACERS

对空气载能辐射空调房间与室外环境的换热过程进行了理论研究及数值模拟，得出了采用修正系数法计算该空调系统冷、热负荷。

A simplified correction coefficient method for load calculation of ACERS has been obtained.

$$\eta = \frac{Q_{CFD}}{Q_{traditional}(W)}$$

表一 冬季热负荷比 Table1 The heating load ratio in winter

Position	Southern wall 南外墙	Southern window 南外窗	Eastern wall 东外墙	Western wall 西外墙	Heating load 热负荷
$Q_{CFD}(W)$	392.7	30	252.7	263.3	938.6
$Q_{traditional}(W)$	485.3	34.5	344.1	313.7	1177.6
η	80.92	86.96	73.44	83.93	79.70

表二 夏季冷负荷比 Table2 The cooling load ratio of different time in summer

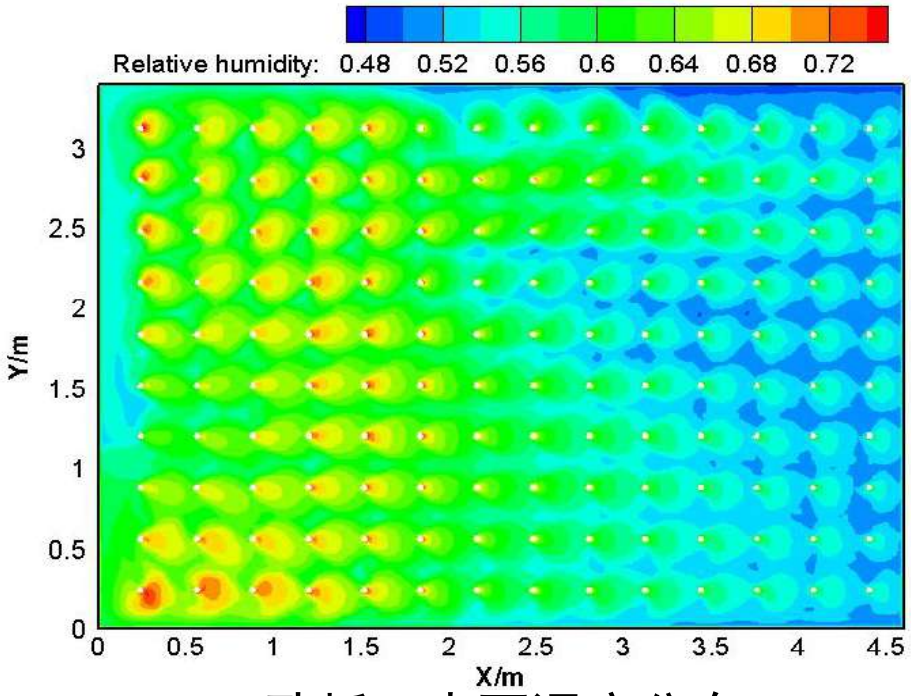
Time	8:00	9:00	10:00	11:00	12:00	13:00
$Q_{CFD}(W)$	743.26	937.9	1007.5	999.96	982.41	1010.75
$Q_{traditional}(W)$	996.1	1215.9	1277.9	1289.5	1264.2	1334.1
η	74.62	77.14	78.84	77.55	77.71	75.76
Time	14:00	15:00	16:00	17:00	18:00	
$Q_{CFD}(W)$	1082.53	1105.39	1126.6	1153.47	925.09	
$Q_{traditional}(W)$	1431	1481.1	1500	1538.4	1304.3	
η	75.65	74.63	75.11	74.98	70.93	

采用修正系数法计算空气载能辐射空调系统夏季负荷时，修正系数的取值为0.75，计算冬季热负荷时，修正系数为 0.8。

The results indicate that the load correction coefficient of ACERS is about 0.75 in summer and 0.8 in winter.

Gong G, Liu J, Mei X. Investigation of heat load calculation for air carrying energy radiant air-conditioning system. Energy and Buildings, 2016, 138:193-205.

2.2 空气载能辐射空调结露特性Condensation analysis of ACERS



孔板下表面湿度分布

Relative humidity distribution on the lower surface of orifice plate

- 模拟研究发现，在孔板下表面存在厚度为6-8cm的具有良好防结露效果的低温近壁边界区。

There is a 6-8cm anti-condensation effect area on the lower surface of the orifice plate of ACERS.

- 相同的室内温湿度参数（28ºC，65%）条件下，空气载能辐射空调孔板表面空气临界露点温度可到11.8-14.5ºC，传统辐射空调系统在20.8ºC左右，比孔板末端高6.3-9.0ºC。

Under the same indoor operating conditions (T=28ºC,R=65%), the maximum value of dew point temperature of ACERS is much lower than that of the traditional radiant air conditioning system.

因此空气载能辐射空调系统夏季供冷时防结露效果显著。

The ACERS can effectively prevent condensation during cooling in summer.

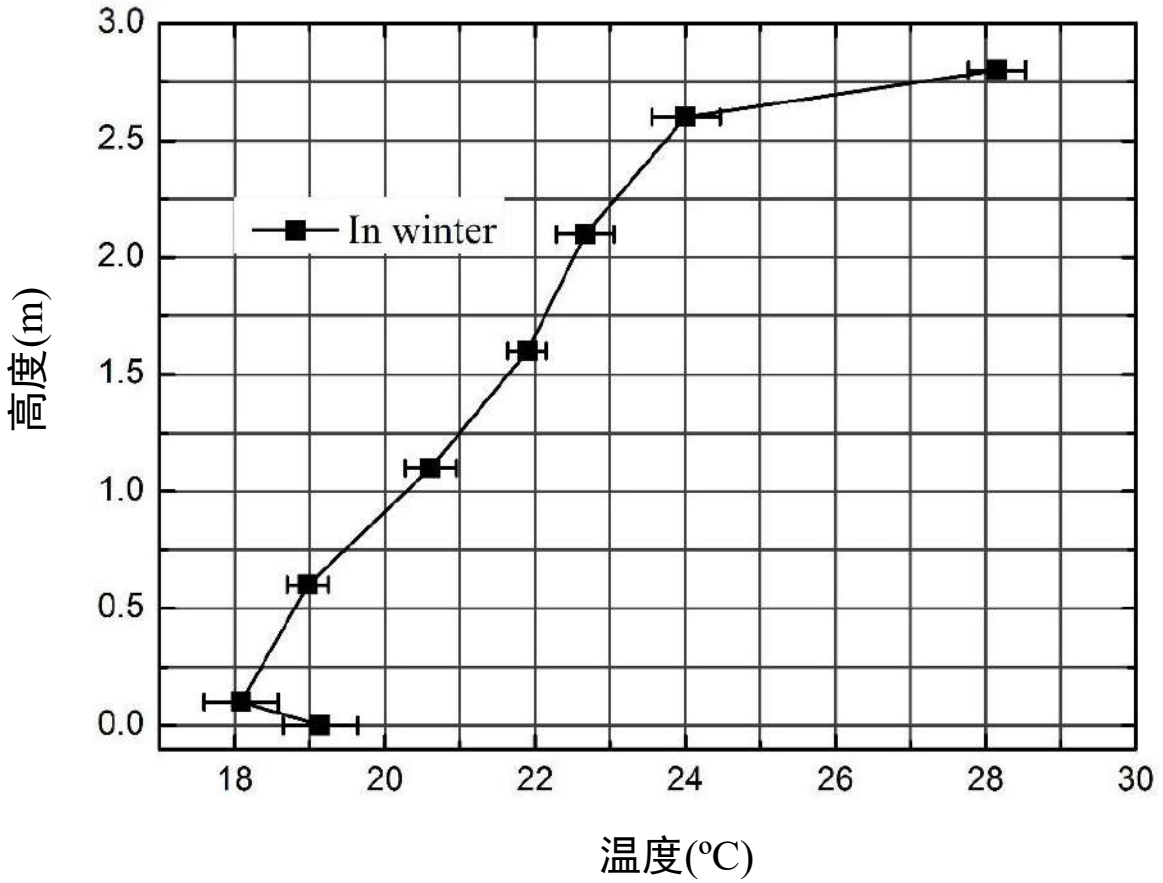
Liu J, Gong G, et al. Investigation of operation performance of air carrying energy radiant air-conditioning system based on CFD and thermodynamic model[J]. Building Simulation, 2018(7):1-15.

以湘能大厦办公室空气载能辐射空调系统的热舒适性研究

Thermal comfort investigation of ACERS in an office of Xiangneng Building

湘能大厦空气载能辐射空调系统应用示范

Application of ACERS in Xiangneng Building



空气载能辐射空调室内温度垂直梯度

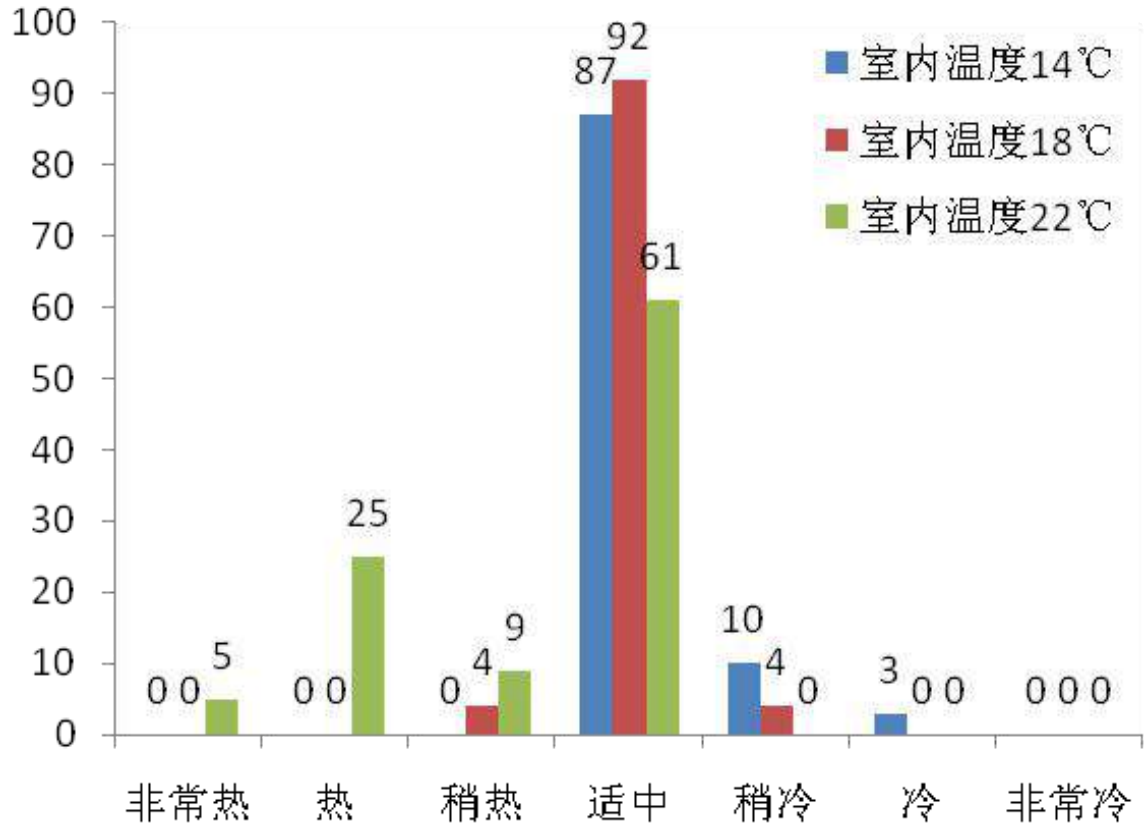
Vertical variations of temperature in winter in ACERS

由图可知，位于吊顶下的2cm以内温度梯度较大，主要因为在辐射吊顶表面附近有着较强的换热；在此高度以下，温度几乎成线性分布，在距地0.1m以上到2.5m的范围内温度梯度小于3ºC/m，满足舒适性要求。

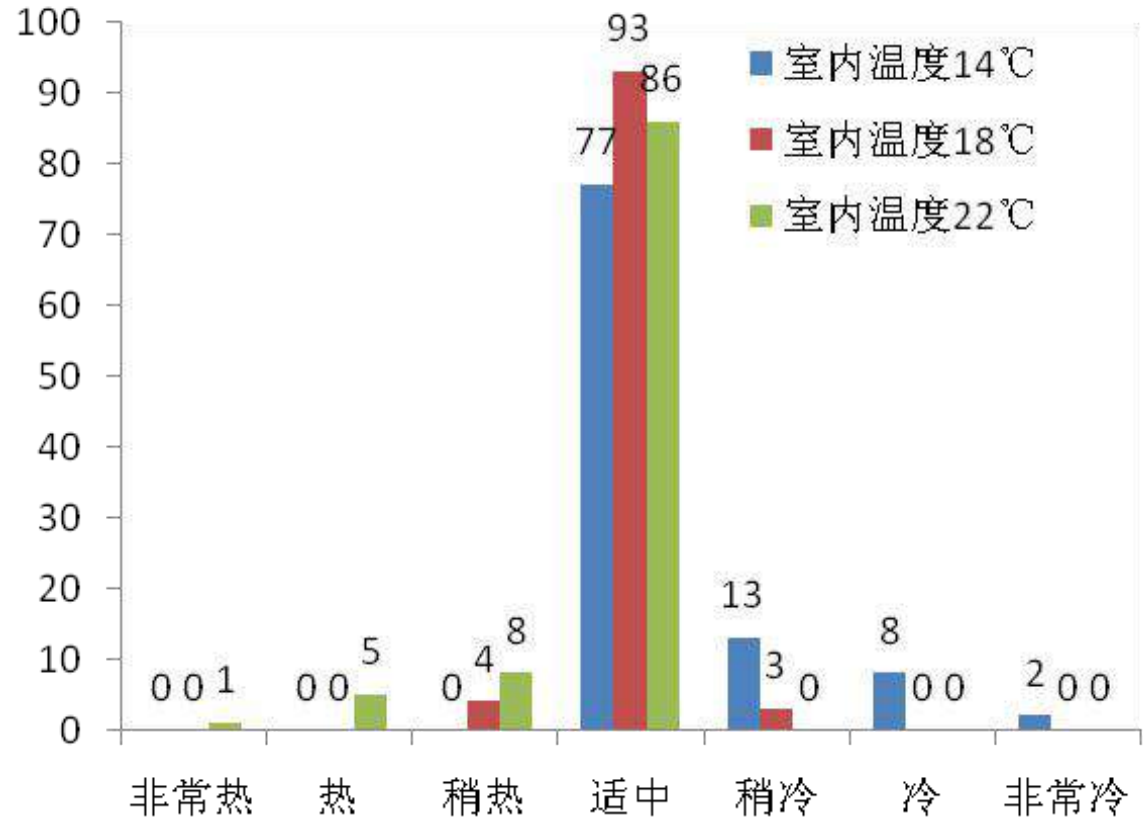
The temperature difference from 0.1m to 1.1m is less than 3ºC/m , which can meet the occupants' comfort requirements.

空气载能辐射空调与传统对流式分体空调的冬季热舒适性问卷调查

Research on human thermal sensation questionnaire of convection air conditioner and ACERS



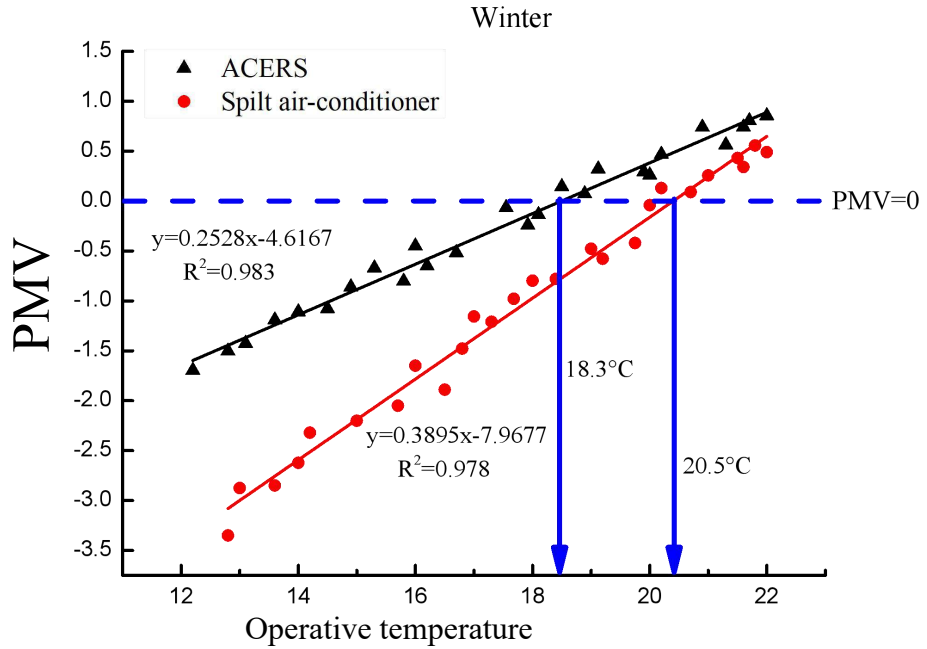
(a) 传统对流式空调系统 Convection air conditioner

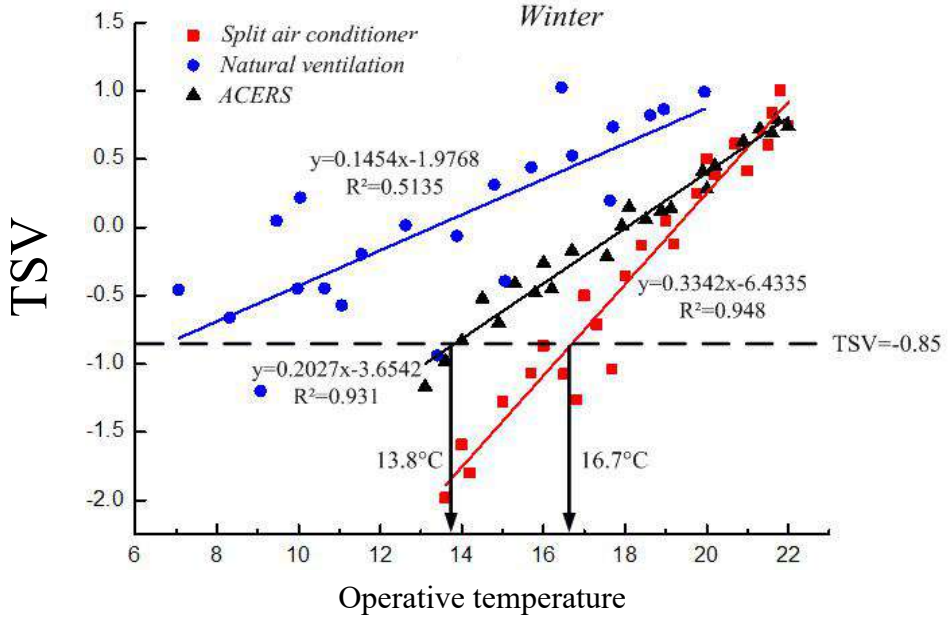


(b) 空气载能辐射空调系统 ACERS

空气载能辐射空调与传统对流式分体空调的冬季热舒适性对比

Comparison of thermal comfort between ACERS and convective air conditioner in winter





左图计算结果表明， 冬季空气载能辐射空调的热舒适中性温度为18.3ºC，对流式空调为20.5ºC。

Comfortable neutral temperature of ACERS is 18.3ºC in winter and that of the convective air conditioner is 20.5ºC.

右图问卷结果表明，冬季空气载能辐射空调的可接受最低舒适温度为13.8ºC，对流式空调为16.7ºC。

Lowest acceptable comfort temperature of ACERS is 13.8ºC and that of the convective air conditioner is 16.7ºC.

Peng P, Gong G, et al. Investigation on thermal comfort of air carrying energy radiant air-conditioning system in south-central China. Energy and Buildings.(Accepted)

3 空气载能辐射供暖应用案例 Application of ACERS

空调设置温度均为21°C时，空气载能孔板辐射末端与传统对流式末端的对比如下：
Comparison between ACERS and convective air conditioner in winter

	空气载能辐射空调ACERS	传统对流式空调 Convection air conditioner
供暖面积 Heating Area (m2)	45	20
单位面积供暖量 Heating unit area (W/m2)	77.4	52.3
耗电量 Energy consumption per hour (KW)	2.01	1.98

由上可知，空气载能孔板辐射末端比传统末端的单位面积供暖量提高了约48%。

在耗电量相差不大时，空气载能辐射末端的供暖面积约为传统末端的2倍，因此空气载能辐射末端单位供暖面积下**耗电量少、节能性高。**

- The heating unit area of ACERS increases by about 48% compared to the convention air conditioner.
- The heating area of ACERS is **about twice** that of convection air conditioner, but the energy consumption of the two system is not much different. Therefore, the ACERS **consumes less power** per unit area and has **high energy efficiency**.

3 空气载能辐射供暖应用案例 Other application of ACERS

药检所 Application in a pharmacy

湖南大学红叶楼 A residential building in HNU campus

湖南大学空气载能辐射空调实验室
ACERS Laboratory in Hunan university

复合式空气载能辐射空调（顶板+侧墙）应用于韶山办公楼
Composite ACERS (Ceiling + Side wall) in Shaoshan

4 总结 Conclusion

空调空气载能辐射空调系统作为一种辐射末端形式，可满足冬季供暖、夏季制冷的双重需求，具有**一体化末端**特点。在冬冷高湿地区是值得推广的，它有以下优势：

ACERS can realize air conditioning integration with only one terminal in winter and summer. Meanwhile it also has the following advantages:

- ✓ 室内温湿度分布均匀
  Temperature and humidity are evenly distributed
- ✓ 无吹风感、热舒适性高
  No draft sensation, good thermal comfort
- ✓ 安装形式方便多样、低成本、易维护
  Various installation forms, low cost, easily maintenance
- ✓ 可有效解决传统辐射空调夏季易结露的问题
  Prevent condensation of radiant cooling ceiling

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进一步深入研究：
Future study

- 空气载能辐射空调在不同通风形式下室内空气品质和气流组织的研究。

The indoor air quality and airflow organization of ACERS under different ventilation modes.

- 对于高湿地区而言，不仅需要开展冬夏一体化的空调系统的研究，还需要开展围护结构蓄能和调湿技术的相关研究。

Research on energy storage and humidity control technologies for envelope structures.

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Thanks for your listening !

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