Energy Technologies Area Lawrence Berkeley National Laboratory

Technical analysis progress for multi-split AC(HP) energy efficiency improvement
多联机空调(热泵)能效提升的技术分析进展

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April 28, 2019

Acknowledgements 致谢

- National Development and Reform Commission (NDRC)
  中国国家发改委
- China National Institute for Standardization(CNIS)
  中国标准化研究院
- Energy Foundation China (EFC)
  中国能源基金会
- Kigali Cooling Efficiency Program (K-CEP)
  基加利制冷能效项目
- Institute for Governance and Sustainable Development(IGSD)
  治理与可持续发展研究所

Outline

- Introduction and Project Status 项目介绍
- Research results 研究结果
- Key Findings and discussions 主要结论

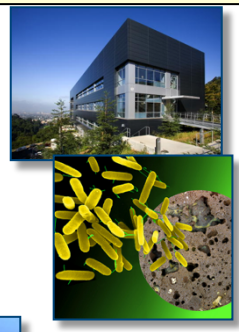
Introduction to Lawrence Berkeley National Laboratory
劳伦斯伯克利国家实验室简介

Managed by the University of California for the United States Department of Energy 由加州大学协助美国能源部负责管理

Lawrence Berkeley National Laboratory

13 — Nobel Prizes 诺贝尔奖获得主
13 — National Medal of Science recipients 美国国家科学奖章获得者
3,300 — Employees 员工
200 — Site acreage 占地面积

- Dedicated to solving the most pressing scientific problems facing humankind. 致力于解决人类所面临的最紧迫的科学问题。
- More than two decades of work internationally on clean energy and climate policy, appliances, buildings, transport, industry, air quality. 专注于全球清洁能源和气候政策、电器、建筑、交通、工业、空气质量等研究二十多年。
- Technical Support to US DOE Energy Efficient Appliance Standards Rulemakings. 为美国能源部节能电器标准制定提供技术支持
- Designed superefficient refrigerators during CFC transition under Montreal Protocol. 蒙特利尔议定书要求的CFC制冷剂替换过渡期，曾设计超高效冰箱
- Technical Support to China, India, Mexico, Brazil, Egypt and Indonesia to revise air conditioner standard.为中国、印度、墨西哥、巴西、埃及和印度尼西亚空调标准修订提供技术支持
- Technical Support to China National Institute of Standardization (CNIS) to revise multi-split air conditioner standard.为中国国家标准化研究所(CNIS)修订多联机空调标准提供技术支持


LBNL Team 项目团队成员

Nihar Shah, Project Lead 项目主管
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Energy Studies Group
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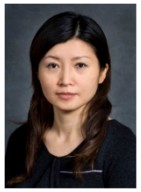

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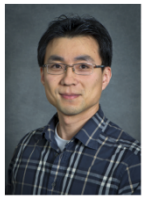
中国能源研究室主任



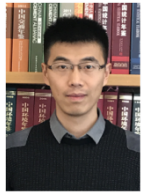
Won Young Park,
Market Assessment 市场评估
Liaison with global
manufacturers 对接国际厂商

Nihan Karali
Regulatory Analysis and Tools
规范分析和软件开发

Jiang Lin, Project co-Lead
项目副主管

Nina Zheng Khanna

Liaison with CNIS 对接CNIS
Regulatory Analysis and Tools
规范分析和软件开发



Chao Ding
Air Conditioner Design Simulation
& Testing 空调器设计模拟和测试
Liaison with Chinese manufacturers
对接中国厂商

Project Overview and Status 项目概况及进展

- Market Assessment 市场调研 (Q1 - Q3 2018)
  - ❑ Completed report, available online 完成报告，网上可以下载报告全文
- Technical Analysis to support VRF standards and labeling (Q3 2018 - Q2 2019)

  技术分析以支持VRF多联机标准及标识
  - ❑ Developed cost-efficiency curve analytical framework for baseline model
    开发了基准制冷量的成本-能效曲线分析框架
  - ❑ Verifying data inputs, scaling factors and developing cost-efficiency curves for additional capacity sizes 正在为其他制冷量的模型校验输入参数、折算系数，并开发成本-能效曲线
  - ❑ Selected VRF testing planned for early Q2 2019 制定了2019年第二季度的测试计划
  - ❑ International policy design for standards and labeling 国际法规标准及标识制定 (Q1 2019-Q4 2019)
- Support implementation and evaluation of market transformation impact

  支持实施及评估市场转型的影响 (Q2 2019 - Q4 2020)
- Support procurement and policy roadmap with subnational pilot demand response program for smart ACs 支持对智能空调地方政府需求响应项目试点的采购和法规规划图 (Q2 2019 - Q2 2020)

Detailed Flow Diagram of the Methodology 详细技术路线

Identification of advanced components and component packages 确定高效部件和系统

AC DESIGN MODULE

Simulations using VapCyc Tool 空调设计模拟，采用VapCyc软件

AC Testing 空调性能测试

Efficiency improvement of advanced components 高效部件的能效提升

Cost of advanced components 高效部件的成本

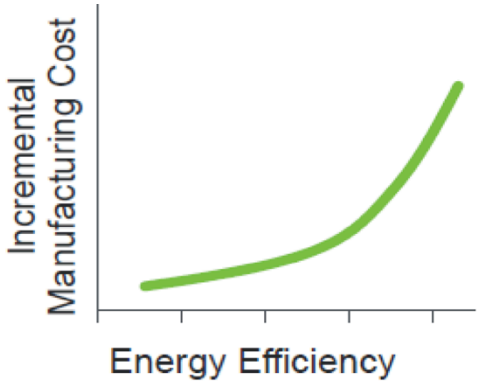
COST CURVE & LIFECYCLE ANALYSIS MODULES

Manufacturing cost 生产成本
Incremental retail price 售价增量
Energy savings 节能量
Bill savings 用电省钱量
Payback period 成本回收期

Least LCC cost design options per efficiency rating 基于能效水平的最低生命周期成本设计方案

Recommendation for Cost-effective level of efficiency for standard

为具有成本效益层级的能效标准提供建议



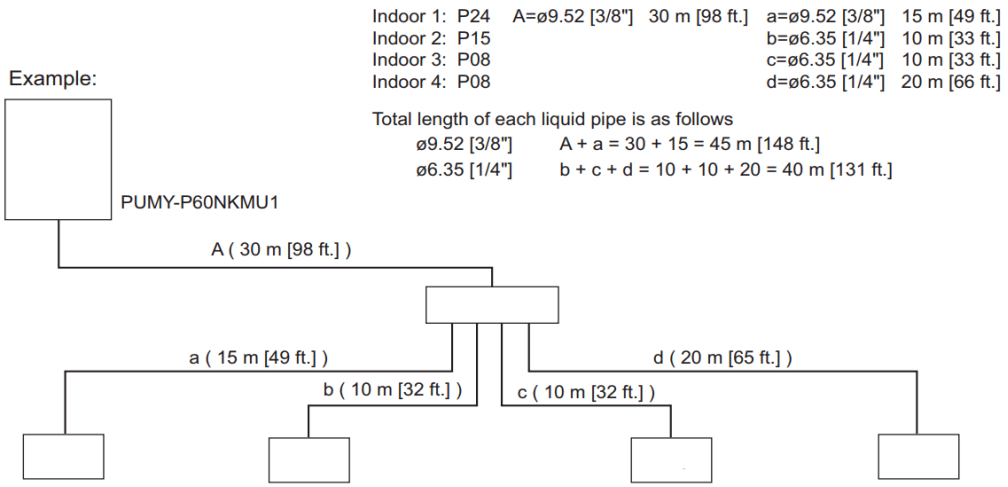
Component change for low-GWP refrigerant transition 制冷剂变更所需的部件改变

REFRIGERANT MODULE

Identification of low-GWP refrigerant transition 低GWP制冷剂过渡的确认

Ductless mini VRF system: 14 kW capacity - 4 indoor units
小型VRF系统：制冷量14 kW-4台室内机

Refrigerant (R410A) (kg)	4.8
Number of outdoor units	1
Number of indoor units	4
Capacity (BTU/h)	48000
Capacity (kW)	14.0
Power input (kW)	3.69
EER (W/W)	3.81
Indoor unit capacities (kW)	
1	2.6
2	2.6
3	3.5
4	5.3
Number of headers	1
Number of joints	0
Piping length (m)	
Ø9.52 [3/8"]	45.0
Ø6.35 [1/4"]	40.0
Additional refrigerant charge (kg)	6.1



Source: *Mitsubishi Electric Corporation. 2016. Air Conditioning Systems – City Multi Data Book.*

Baseline manufacturing cost and other assumptions used in the analysis :
基线模型制造成本和其他假设
Ductless mini VRF system: 14 kW capacity - 4 indoor units
小型VRF系统：制冷量14 kW-4台室内机

Component	Manufacturing Cost (RMB)
Fan motor	320
Fan Blade	133
Heat Exchanger	1216
Compressor (VSD)	2370
Refrigerant	509
Sheet metal	363
Valves	224
Header/Joint	200
Pipeline	385
Controller	950
Other	492
TOTAL	7162

Note: *Manufacturing cost estimates listed are LBNL's current best guestimates for a 14 kW and 4 indoor units ductless mini VRF system.*

Assumptions		
Consumer discount rate	2.25	%
Hours of use	1569	hrs/yr
Lifetime years	12	yrs
Electricity price	0.55	¥/kWh
Annual increase rate of electricity price	1	%
All makrup	100	%
Incremental price sensitivity (e.g., ±50%)	50	%

Options to further improve efficiency of VRFs with associated costs: Ductless mini VRF system: 14 kW capacity - 4 indoor units

进一步提高VRF能效的设计方案及相关成本: 小型VRF系统, 制冷量14 kW-4台室内机

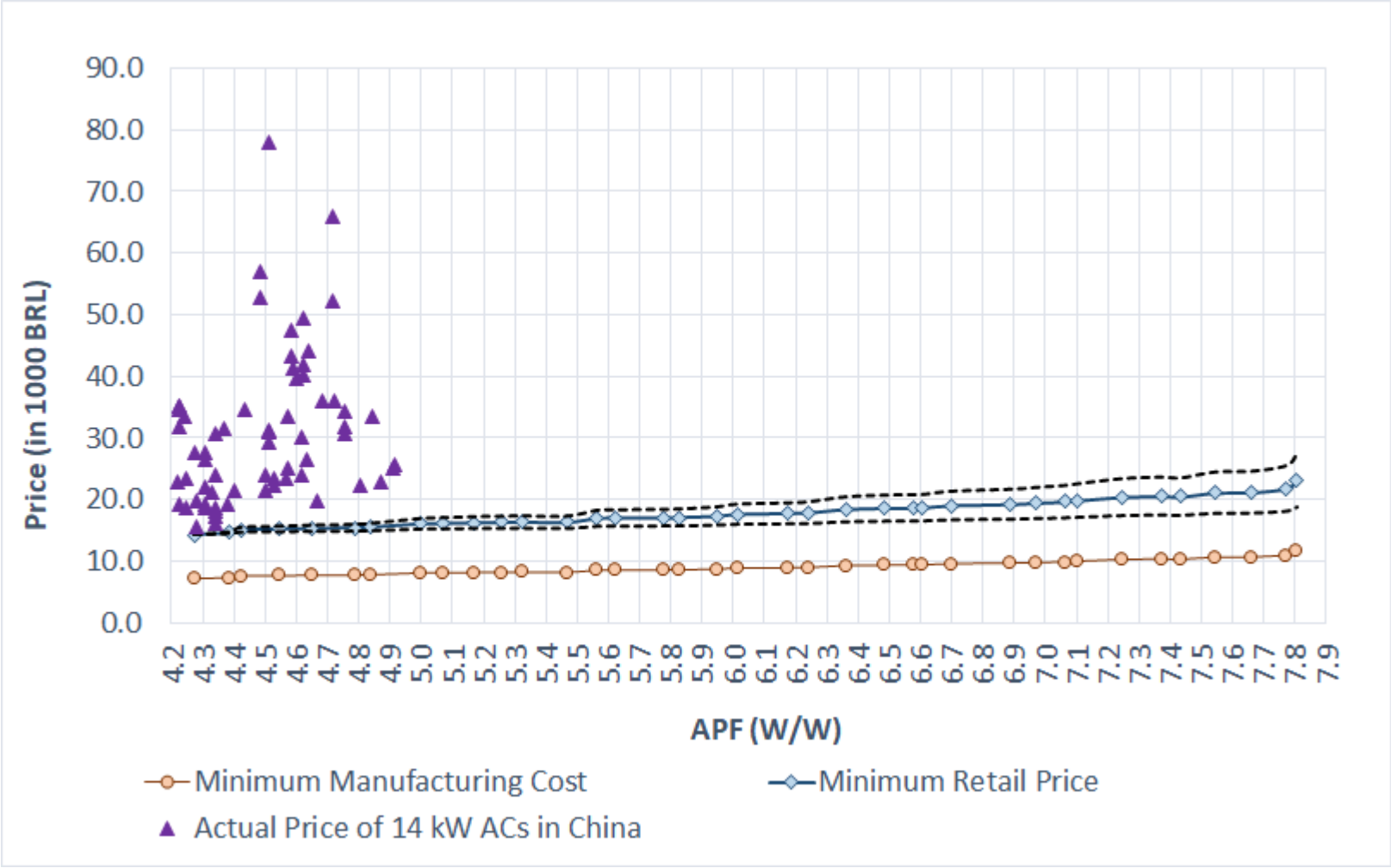
	Component	Baseline Mfg Cost (RMB)	Incremental Mfg Cost (RMB)	Retail Price Increase from Base Case (RMB)	Energy Savings from Baseline
Baseline VSD Compressor	4.1 EER Compressor	1010			
Compressor 1	4.3 EER Compressor	1170	160	320	5.9%
Compressor 2	4.5 EER Compressor	1530	520	1040	11.0%
Compressor 3	4.7 EER Compressor	1890	880	1760	15.6%
Compressor 4	4.9 EER Compressor	2520	1510	3020	20.4%
Baseline DC inverter	Direct Current (DC) variable speed drive for compressor	1360			
All DC inverter	Direct Current (DC) variable speed drive for compressor and fans	1760	400	800	5.3%
Baseline Heat Exchanger (HE)	-	1216			
HE 1	UA of both HEs increased by 20%	1675	459	918	8.3%
HE 2	UA of both HEs increased by 40%	2055	839	1678	14.2%
HE 3	UA of both HEs increased by 60%	2355	1139	2278	19.0%
HE 4	UA of both HEs increased by 80%	2571	1355	2710	22.3%
HE 5	UA of both HEs increased by 100%	2931	1715	3430	25.8%

Note: *Manufacturing cost estimates listed are LBNL's current best guestimates for a 14 kW and 4 indoor units ductless mini VRF system. (1) Baseline compressor has 2.9 EER. (2) UA represents the product of overall heat exchange coefficient (U) and heat exchanger area (A).*

Manufacturing cost and retail price increase per efficiency improvement: Ductless mini VRF system: 14 kW capacity - 4 indoor units

制造成本和零售价随能效提升增加：小型VRF系统, 制冷量14 kW-4台室内机

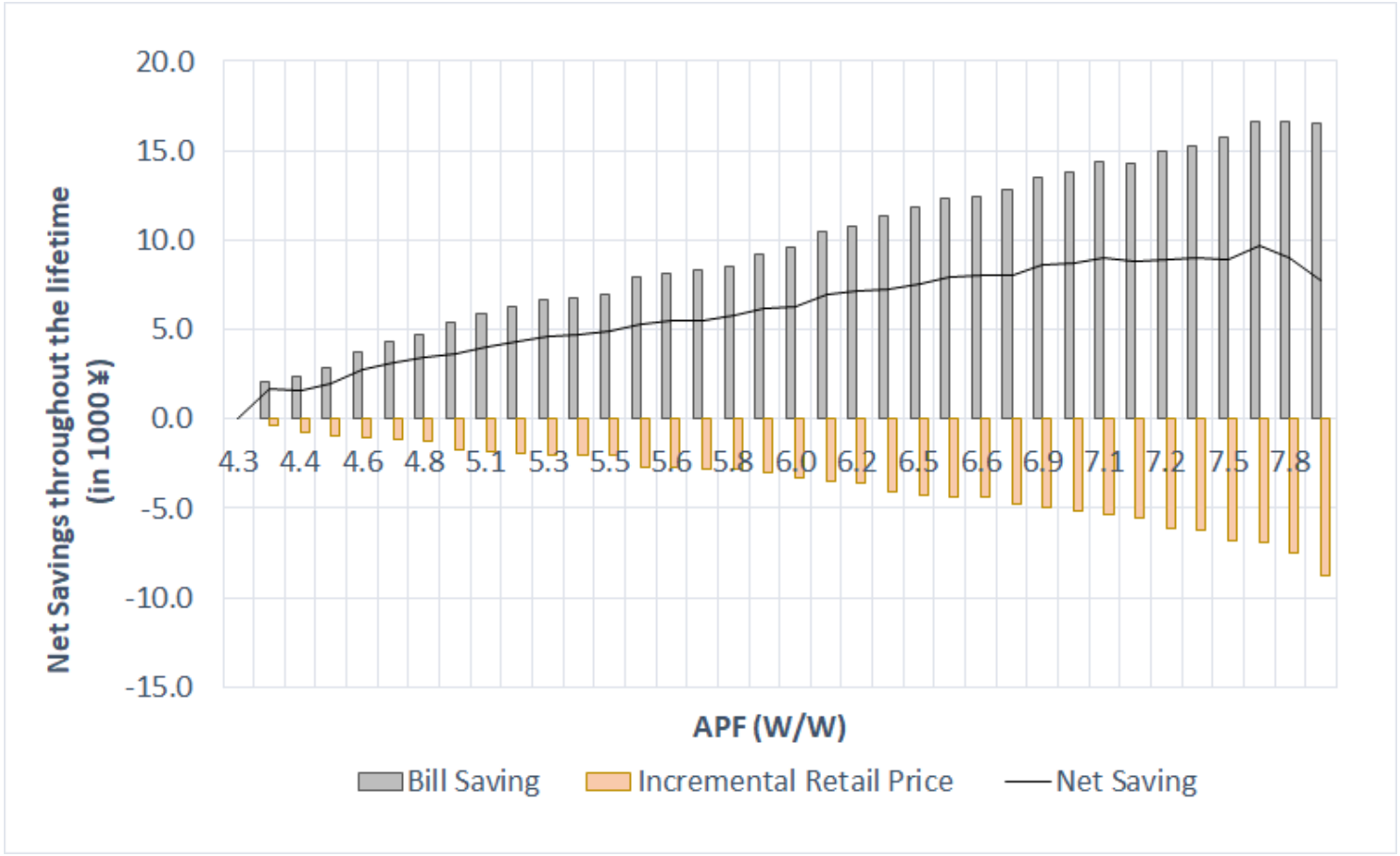
PRELIMINARY RESULT 初步结果



Net savings per efficiency improvement 能效提升净收益:

Ductless mini VRF system: 14 kW capacity - 4 indoor units

PRELIMINARY RESULT 初步结果

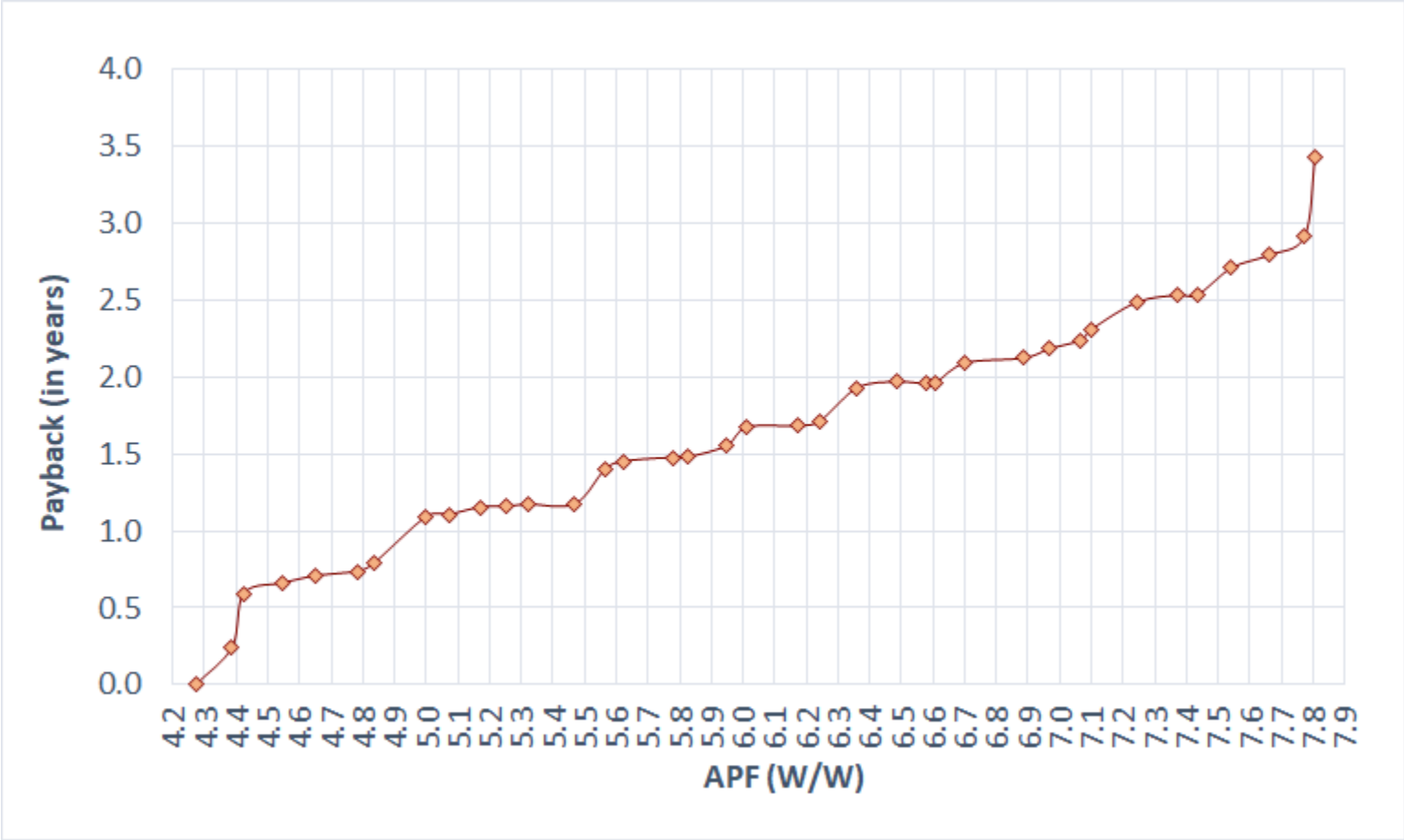


Efficiency improvement up to APF of 7.5 is cost effective from consumer standpoint indicating very significant cost-effective efficiency improvement potential. 从消费者角度，机组能效提升到APF7.5，都是符合成本效益的，具有非常显著的能效提升潜力.

Payback per efficiency improvement 能效提升回收期:

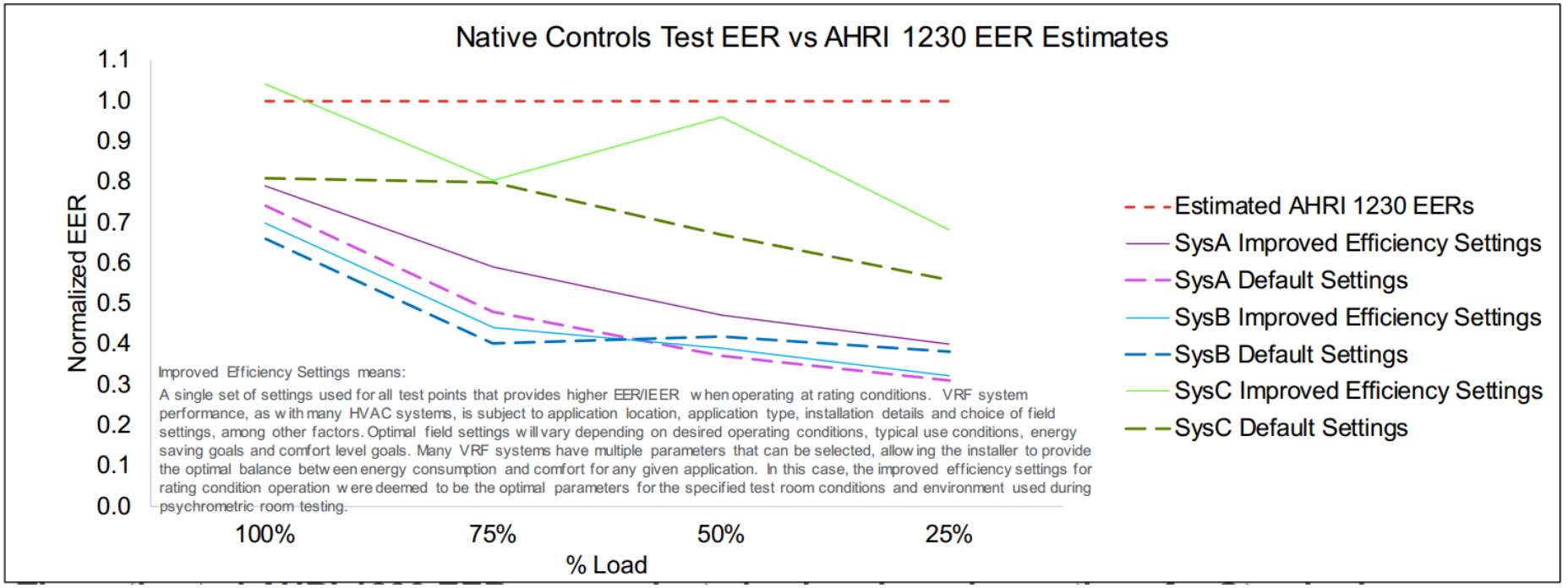
Ductless mini VRF system: 14 kW capacity - 4 indoor units

PRELIMINARY RESULT 初步结果



DOE VRF rulemaking update 美国能源部VRF标准制定情况

- The Variable Refrigerant Flow Multi-Split Air Conditioners and Heat Pumps Working Group is proposing a new Federal test procedure for VRF multi-split systems. VRF多联机空调和热泵工作组正在为VRF多联机系统提出一个新的联邦测试方法。
- Compared with the current AHRI 1230 test, a new Controls Verification Procedure is proposed. 与现有的AHRI 1230测试相比，提出了一种新的控制测试方法。



Conclusions and suggestions 结论和建议

- Completed market assessment report 已完成市场分析报告
- Developed cost-efficiency curve analytical framework 开发了基准制冷量的成本-能效曲线分析框架
- Developing cost-efficiency curves for small capacity ductless mini VRF and ducted VRF systems 正在开发小型家用VRF多联机和风管式VRF系统的成本-能效曲线
- Preliminary results indicate that efficiency improvement up to APF of 7.5 is cost effective from consumer standpoint indicating very significant cost-effective efficiency improvement potential. 初步研究结果表明，从消费者的角度，机组能效提升到APF7.5，都是符合成本效益的，具有非常显著的能效提升潜力.
- In the previous EE standard revision, almost 100% multi-split products on the market met Grade 1 in about 2 years after the standard implemented. It is suggested that the proposed standard is stringent enough, so that models are available in all grades for 3-5 years after the standard is implemented. 在上一版的能效标准修订中，市场上几乎100%的多联机产品在标准实施后约2年内达到了一级能效标准。建议新版能效标准足够严格，标准实施3-5年内，仍存在 不同能级的产品
  - From 2012 to 2016, model-weighted average efficiency (in IPLV) of multi-split ACs have improved by between 53-65%, varying by capacity size class 从2012年到2016年，基于不同冷量大小的多联机空调产品按型号加权平均的综合部分负荷性能系数值(IPLV)提高了53-65%
  - By models: Newest models on the market all exceed Grade 1 efficiency requirements, with model-weighted average efficiency far beyond 2008 MEPS requirements 按型号统计：市场上最新型号都超过了一级能效要求，按型号平均综合部分负荷性能系数远超2008年最低能效标准的要求

			CC≤28kW	28kW<CC≤84kW	CC>84kW
IPLV (W/W)	2015	Model Avg	7.75	7.95	7.10
		Max	9.50	9.20	7.55
		Min	4.60	4.80	5.00
	2016	Model Avg	7.31	8.23	7.92
		Max	9.50	9.20	8.55
		Min	3.95	3.56	6.00

- DOE is proposing a new Federal test procedure for VRF multi-split systems, which may provide useful information for China standard making. DOE正在提出一种VRF多联机新的联邦测试方法，相关信息可能对中国标准制定有帮助

Next Steps and Data Support from Project Partners
下一步计划和需要项目合作伙伴的协调配合

Timeline 下一步计划:

- Complete cost-efficiency curve analysis for multiple capacity models: May 2019
  2019年5月：完成不同冷量的多联机成本-能效曲线分析
- Verify data inputs with testing and manufacturer input: June - July 2019
  2019年6-7月：结合实测数据和厂商反馈验证模型输入参数
- Finalize cost-efficiency curves, impact analysis, and report on technical analysis: August 2019 2019年8月：完成成本能效曲线，影响分析和技术分析报告

- CNIS: joint technical analysis 继续技术分析合作
  Energy efficiency market distribution 市场能效分布
  IPLV-SEER/APF conversion factors 能效评价指标转换系数

- Manufacturers: Cost data, Simulation inputs (compressor map, fan speed, power, etc.) 成本数据、模拟输入数据(压缩机特性，风机风量、功率等)

- EFC: coordination support 协调支持

Thank You!
Questions? Suggestions?

Contact 联系方式:

- Nihar Shah: nkshah@lbl.gov
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Appendix

Ducted VRF system: 17.5 kW capacity - 5 indoor units
风管式VRF系统：制冷量17.5 kW-5室内机

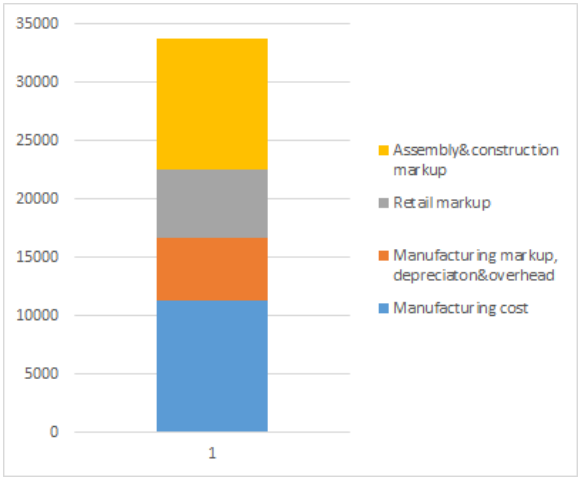
Refrigerant (R410A) (kg)	5.1
Number of outdoor units	1
Number of indoor units	5
Capacity (BTU/h)	60000
Capacity (kW)	17.5
Power input (kW)	4.68
EER (W/W)	3.75
Indoor unit capacities (kW)	
1	2.6
2	2.6
3	3.5
4	3.5
5	5.3
Duct length (m)	
Ø9.52 [3/8"]	45.0
Ø6.35 [1/4"]	60.0
Additional refrigerant charge (kg)	7.8

Source: *Mitsubishi Electric Corporation. 2016. Air Conditioning Systems – City Multi Data Book.*

Baseline manufacturing cost and other assumptions used in the analysis: Ducted VRF system: 17.5 kW capacity - 5 indoor units

基线制造成本和其他假设: 风管式VRF系统, 制冷量17.5 kW-5室内机

Component	Manufacturing Cost (RMB)
Fan motor	400
Fan Blade	167
Heat Exchanger	1520
Compressor (VSD)	4220
Refrigerant	602
Sheet metal	453
Valves	280
Duct	1830
Controller	1188
Other	600
TOTAL	11260



Note: *Manufacturing cost estimates listed are LBNL's current best guestimates for a 17.5 kW and 5 indoor units ducted VRF system.*

Options to further improve efficiency of VRFs with associated costs: Ducted VRF system: 17.5 kW capacity - 5 indoor units

进一步提高VRF能效的设计方案及相关成本: 风管式VRF系统, 制冷量17.5 kW-5室内机

	Component	Baseline Mfg Cost (RMB)	Incremental Mfg Cost (RMB)	Retail Price Increase from Base Case (RMB)	Energy Savings from Baseline
Baseline VSD Compressor	4.1 EER Compressor	2520			
Compressor 1	4.3 EER Compressor	2920	400	1200	5.9%
Compressor 2	4.5 EER Compressor	3320	800	2400	11.0%
Compressor 3	4.7 EER Compressor	3720	1200	3600	15.6%
Compressor 4	4.9 EER Compressor	4120	1600	4800	20.4%
Baseline DC inverter	Direct Current (DC) variable speed drive for compressor	1700			
All DC inverter	Direct Current (DC) variable speed drive for compressor and fans	2200	500	1500	5.3%
Baseline Heat Exchanger (HE)	-	1520			
HE 1	UA of both HEs increased by 20%	2094	573	1720	8.3%
HE 2	UA of both HEs increased by 40%	2442	922	2767	14.2%
HE 3	UA of both HEs increased by 60%	2791	1271	3814	19.0%
HE 4	UA of both HEs increased by 80%	3214	1694	5081	22.3%
HE 5	UA of both HEs increased by 100%	3664	2144	6431	25.8%

Note: *Manufacturing cost estimates listed are LBNL's current best guestimates for a 17.5 kW and 5 indoor units ducted VRF system. (1) Baseline compressor has 2.9 EER. (2) UA represents the product of overall heat exchange coefficient (U) and heat exchanger area (A).*