



建筑调适是什么

What is Building Commissioning

March, 2018





提纲Scheme

- 背景
- 调适是什么
- 感想

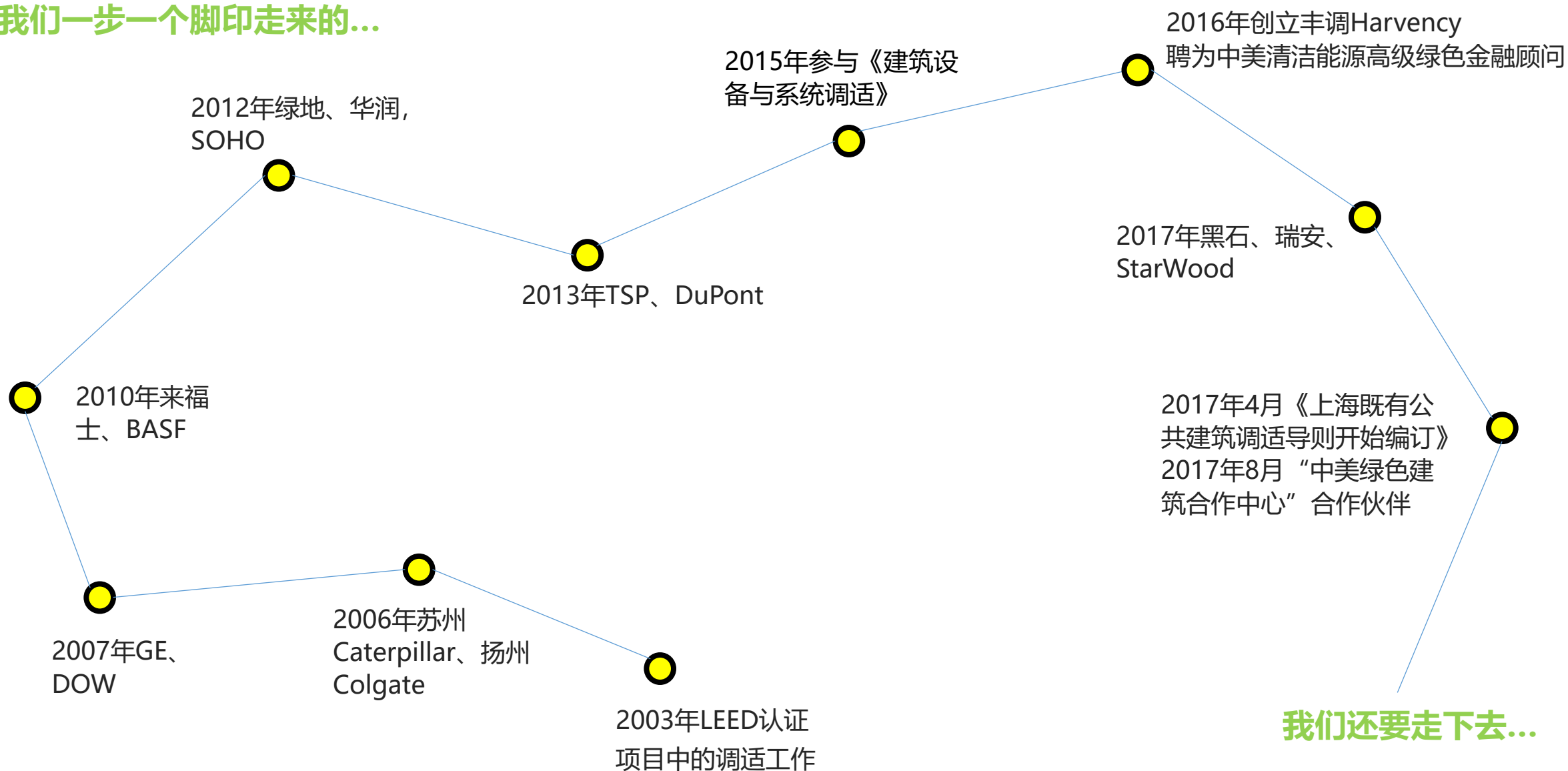
- Background
- What is Building Commissioning, BCx?
- Further Thoughts





发展历程?

我们一步一个脚印走来的...





案例分析?

- 自2006年以来, 公司主要成员以主要项目负责人身份参与超过350个的高能效建筑和调适项目。其中, 钱颖初先生因其对中美清洁能源相关金融做出的贡献, 在2016年被特聘为中美清洁能源高级绿色金融顾问。
- 自2005年以来负责了多个中国最早的商业建筑调试项目, 包括: 高露洁工厂 (扬州)、卡特彼勒工厂 (苏州)、通用电气中国区总部 (上海)、来福士综合体 (成都)、巴斯夫中国区总部大楼 (上海) 等项目;

案例 Case Studies



我们主要成员主导的项目 (美国) Key Members involved Practices in U.S.

建筑类型 Building Type	数量 Number	节能量(\$/ft ² /yr) Energy Saving	费用(\$/ft ²) Cost	简单回收期(yr) Simple Payback
医院 Hospital	6	0.43	0.474	1.1
实验室+办公 Lab + Office	7	1.26	0.368	0.3
教室+办公 Classroom + Office	5	0.43	0.226	0.5
办公楼 Office Building	8	0.22	0.329	1.5
学校 School	2	0.17	0.336	2.0
总计 Total	28	0.54	0.359	0.7

案例 Case Studies



我们主要成员主导的项目 (中国) Key Members involved Practices in China



绿地集团总部, 上海
Greenland Headquarter, Shanghai



上海衡山路十二号豪华酒店
Hengshan Luxury Hotel, Shanghai



深圳来福士
Raffles City, Shenzhen



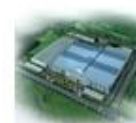
成都来福士
Raffles City, Chengdu



巴斯夫中国区总部, 上海
BASF Headquarter, Shanghai



清华大学苏世民学院
Stephen A. Schwarzman College, Beijing



扬州高露洁
Colgate Factory, Yangzhou



无锡卡特彼勒
Caterpillar Factory, Wuxi



杜克大学昆山校区
Duke University, Kunshan



腾讯总部, 深圳
Tencent Headquarter, Shenzhen



华润总部大楼, 深圳
ChinaLand Headquarter, Shenzhen

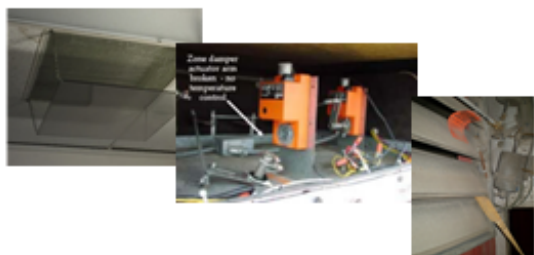


关键技术?

关键技术简介 Brief Intro of Key Strategies

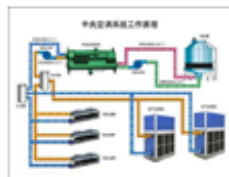
单机调适 Component-level Functional Testing

- 对所有空调设备包括制冷主机、水泵、空调机组、末端设备、传感器、执行器等等，进行功能测试与校正，确保所有设备能正常运行。Customized functional testing for individual HVAC equipment to ensure that all equipment is installed properly and operated as expected.
- 由于我国建筑竣工时没有做过调适，因此往往需要做水力平衡Testing, adjusting and balancing (TAB) for water and air systems based on NEBB standard.



联合调适 Functional Testing for Integrated Operation and Control

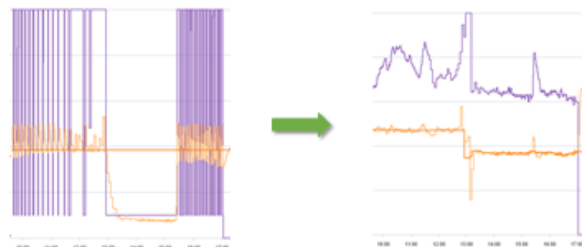
- 对于没有BA的建筑，根据预算优化控制系统设计 (PLC vs. BA) Optimized automation solution for buildings without BAS (PLC vs. BAS)
- 控制回路震荡调适Tuning techniques for PI control loop hunting
- 最优化系统启停Optimal start control for HVAC systems
- 变水量系统优化控制Optimal control algorithms for variable water flow system
- 变风量系统优化控制Optimal control algorithms for variable air volume system
- 1+1<1多台泵联合运行优化控制1+1<1 control strategy for multi-pump system
- 冷冻水系统 (冷却塔风机、冷却水泵、制冷机、冷冻水泵) 联合优化控制Optimized control for the whole chilled water system (cooling tower fans, condenser water pumps, chillers and chilled water pumps)



关键技术简介 Brief Intro of Key Strategies

控制回路振荡调适

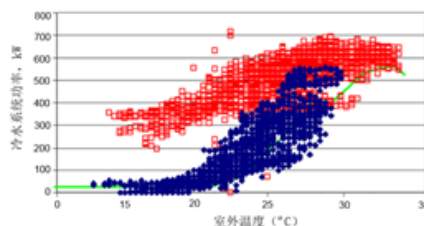
- 问题: PI控制回路适用于线性系统，而空调系统是非线性系统，因此如何使用PI控制器实现稳定的控制对调适顾问的技术要求很高
- 矛盾: 暖通工程师不懂控制，控制工程师不懂暖通系统特性
- 我们的优势: 精通控制的暖通工程师
- 我们的解决方案: Hardware-In-The-Loop动态仿真结合分段线性化



关键技术简介 Brief Intro of Key Strategies

冷水系统调适

- 问题:
 - 传统方法采用定冷却水温度、定冷冻水温度、制冷机与冷却塔、水泵一一对应运行。
 - 人工确定冷机开启的台数、时间
 - 冷却塔风机、水泵均工频运行 (即使有变频器，也基本定频运行)
- 我们的解决方案: 根据各个设备的能效曲线，通过动态仿真找到在不同边界条件下的最优运行参数，从而实现冷水系统的整体优化运行。





是技术不重要么？

调适涉及系统：

- 建筑外围护
- 空调采暖及其自控
- 照明及其自控
- 消防.....

机电占建筑总建安成本15-20%

建筑中小业主投诉一半以上是因为空调问题



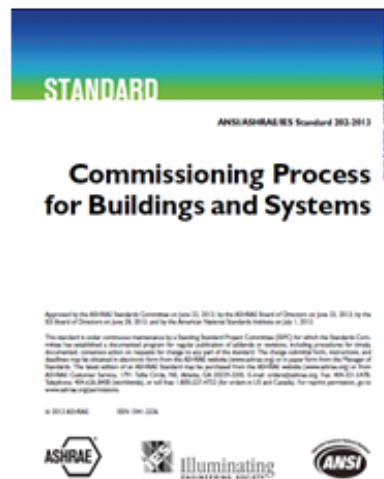


调适是什么? What is Building Commissioning?

定义 Definition

建筑调适是一个确保建筑的性能达到设计指标以及业主预期的过程。它侧重于验证与记录所有需要调适的建筑系统和组件，在计划、设计、安装、测试、运行与维护的过程中，满足业主的项目要求。

运行性能 = 设计预期



内容 Scope of Work

传统调适
Conventional Cx

设计评价
Design review

采购指导，如界面划分、参数等
Procurement support, such as interface clarification

设备的安装及启动测试
Equipment startup testing

水系统及风系统系统平衡测试
Water and air system TAB, Testing and Balance

各系统功能测试及运行，测量其性能
Building system functional testing

各系统控制策略
Controlling logic optimization

系统整体运行
Whole building commissioning

设备及系统操作维护人员培训
Equipment and system operation training

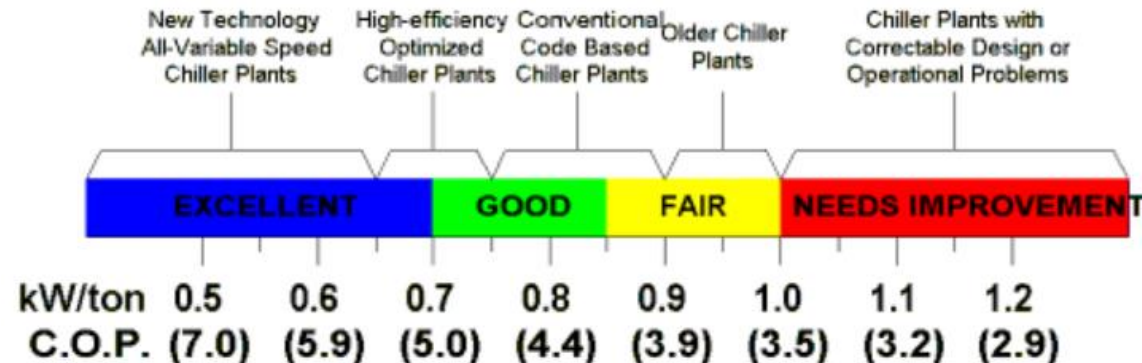
后期系统运行效果回访
Performance review





调适是以结果为导向的

- 节能
- 舒适
- 可靠



AVERAGE ANNUAL CHILLER PLANT EFFICIENCY IN KW/TON (C.O.P.)
(Input energy includes chillers, condenser pumps and tower fans)

Based on electrically driven centrifugal chiller plants in comfort conditioning applications with 42F (5.6C) nominal chilled water supply temperature and open cooling towers sized for 85F (29.4C) maximum entering condenser water temperature. Local Climate adjustment for North American climates is +/- 0.05 kW/ton

案例分析 Case Study

上海某豪华精选酒店建筑整体调适

Building Commissioning for 5-Star Luxury Hotel, Shanghai



- 超豪华五星级酒店 Luxury 5-Star Hotel
- 2012年开业 Opening: 2012
- 管理方: 喜达屋 Operation: Starwood
- 建筑面积: 51,094平米, 地上五层, 地下三层 GFA: 51,094, 5-story above ground and 3 underground
- 主要功能区: 171间/套房, 1,300平米会议厅, 425平米宴会厅, 7个多功能会议室, 24小时开放健身房, 室内恒温游泳池
- Main function: 171 rooms, conference rooms 1,300sqm, banquet hall 425sqm, 7 multi-function meeting rooms, 24-hour gym, indoor heated swimming pool
- 暖通空调系统: HVAC
 - 冷源: 三台2743kW离心式水冷机组, 6°C/12°C冷冻水供应制冷需求;
Chilled water system: Three 2,743 kW centrifugal water cooled chillers with design chilled water supply/return temperatures of 6°C/12°C.
 - 热源: 两台5吨蒸汽锅炉, 经汽-水板换60°C/50°C热水供应采暖需求;
Hot water system: Two 5-ton gas steam boiler through heat exchanger to produce 60°C/50°C hot water.
 - 空调末端: 客房采用风机盘管+新风, 其余部分为全空气系统;
Terminal units: FCU + Fresh air unit for guest rooms and others using all air systems.
 - BA: 末端采用江森自控, 机房采用施耐德自控系统。
BAS: terminal systems using JCI and central plant using Schneider.
- 调适进度: 2017年03-08月施工完毕, 调适部分工作完成
- Commissioning service status: Installation Mar-Aug. 2017, part of scope of work done

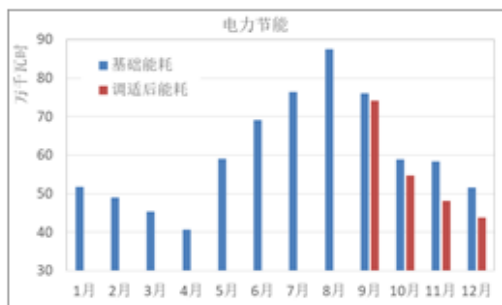
上海某豪华精选酒店建筑整体调适

Building Commissioning for 5-Star Luxury Hotel, Shanghai

收益Benefits

- 节能 Energy Saving (2017年9-12月):
 - 节能率9.9% total 9.9%
 - RMB 250,000;
- 舒适性提升 Improvement of thermal comforts

投入Cost • RMB1.8m



主要调适措施 Commissioning Strategies

- 水系统与风系统平衡; Water/air system balancing
- 冷冻/冷却水泵加装变频器, 实施了基于管路特性的水泵变频优化控制策略; Install VFDs for chilled water and condenser water pumps. Implement system curve based optimal control sequences for the variable speed pumps;
- 动态变冷冻水温度控制策略; Implement chilled water supply temperature reset strategy;
- 基于室外湿球温度的冷却塔风机优化控制; Implement wet-bulb temperature based cooling tower fan control;
- 冷却塔板换直接供冷控制; Implement water-side economizer;
- 基于回风温度的空调机组变风量控制; Implement return-air temperature based variable speed fan control;
- 两套BA系统整合到同一个BA平台; Combine the two BASs into one platform.
- 所有BA系统传感器校准与电动执行器检修。Calibration of all sensors and actuators.

案例分析 Case Study

某智慧园区办公楼冬季热舒适性调适

Thermal Comfort Commissioning for Office Buildings, Shanghai



- 项目名称: 上海某智慧园区
- Project Name: A Knowledge Center, Shanghai
- 项目简介: #3楼共五层, 约7,200平方米; #10楼共七层, 约9,300平方米
- Project Brief: #3(5 floors, about 7,200sqm GFA); #10(7 floors, about 9,300sqm GFA)
- 竣工时间: 2006年 Completion: 2006
- 主要功能区: 办公、教育培训 Main function: Office and education
- 暖通空调系统: HVAC Brief
 - 热源: 三台燃气锅炉集中热水92°C/72°C, 经分水器送至2路末端采暖, 经空调板换60°C/50°C热水供应空调需求, 经地源板换85°C/70°C热水供应散热器需求。
 - Hot water system: three gasboilers with hot water supply and return temperatures at 92°C/72°C. One dedicated heat exchanger supplies hot water for the fan coils with secondary hot water supply and return temperatures at 60°C/50°C. Another dedicated heat exchanger produces 85°C/70°C for the underfloor fin tubes.
 - 末端: 新风空调机+散热器
 - Terminal units: Outside air units + fin tubes

项目诉求 Owner's Project Requirements (OPR)

- 用户反应冬季工况下, 热舒适性非常差, 散热器采暖空间首层温度偏低, 最不利温度仅能达到13度左右, 并存在严重的冷热不均现象。
- Bad thermal comfort in Winter. The area served by the underfloor fin tubes had poor temperature control and the worse case is only 13 degree when outdoor temperature is below zero degree. Severe unbalanced heating supply was also observed.

工作职责 Scope of Work (SoW)

- 三周内(赶在极端温度到来之前)解决此问题, 总体升温达到6度
- Solve the problems in 3 weeks and increase the room temperature by 6 degree
- 尽可能的投入解决此问题, 投入的软硬件, 今后运营尽量能用, 不能浪费
- Limited budget. All added software or hardware shall be useful for operation, but not be temporary.
- 不能影响正常办公; Normal operation cannot be interrupted.

某智慧园区办公楼冬季热舒适性调适

Thermal Comfort Commissioning for Office Buildings, Shanghai

调适效果 The Result

原来 Before



现在 After



夸张了
Joke

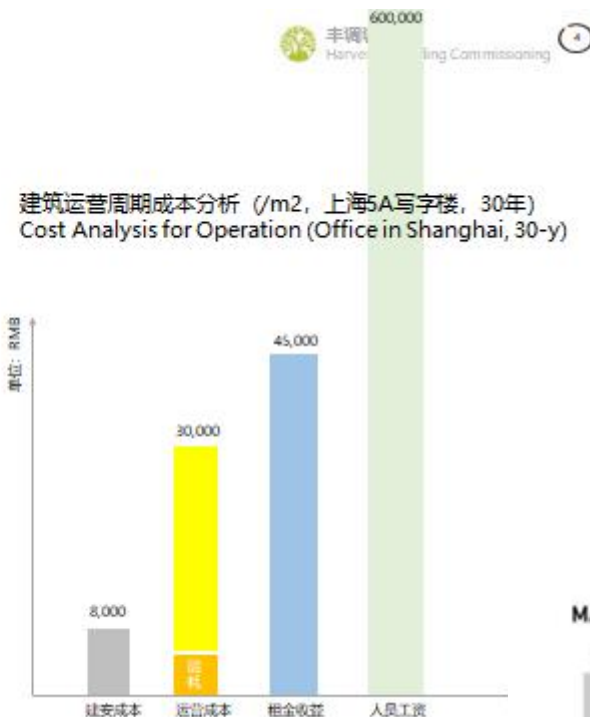


调适是资产增值的重要手段

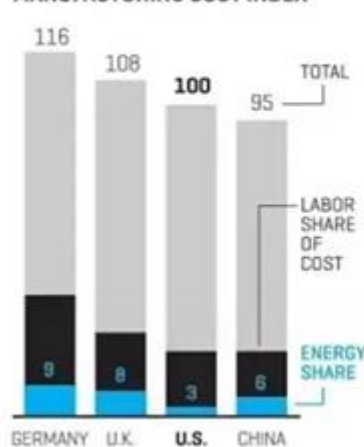
资产建设
Asset Development



资产管理
Asset Management



MANUFACTURING COST INDEX



注: 波士顿咨询公司2013年的显示数据



购物中心、办公楼（一线城市）的IRR在5~10%

能源设施的智慧管理带来的能耗费用降低可以提升IRR0.3~1.2%!
.....但同时能够提升的舒适性很难量化。

绿色金融助力建筑节能

Green Financing and Building Energy Efficiency

Oct 17, 2017



绿色建筑技术或产品的金融属性

Financial attributes of Green building Technology or Product

绿色建筑技术 Green Building Technologies

LED灯更换 Replacement
制冷机更换 Chiller replacement
变频器 Variable flow driver
太阳能光电 Solar PV
贴膜 Membrane
能源中心 Energy Center

内部贴现率IRR

40%-60%	+考虑社会效益 social benefits considered 41%-61%
10-15%	11-16%
30%-50%	30%-50%
9%-12%	10%-13%
8%-12%	10%-14%
5%-9%	8%-15%

建筑整体调试 Building Commissioning

30%-40% 31%-41%



绿色建筑技术或产品的金融属性

Financial attributes of Green building Technology or Product



- 1 LED灯更换 Replacement
- 2 制冷机更换 Chiller replacement
- 3 变频器 Variable flow driver
- 4 太阳能光电 Solar PV
- 5 贴膜 Membrane
- 6 能源中心 Energy Center
- 7 建筑整体调试 Building Commissioning





调适是实现资产风控的有力工具

设计

设备配置冗余度高
和运营脱节

施工（安装）

团队质量参差不齐
相互配合没有默契

采购

责任界面划分模糊
验收质量限定不清

运营

长短期效益不能平衡
舒适、节能问题无法解决

改造

“去” “留” 的度把握不准
因地制宜较差

设计评价
Design review

采购指导，如界面划分、参数等
Procurement support, such as interface clarification

设备的安装及启动测试
Equipment startup testing

水系统及风系统系统平衡测试
Water and air system TAB, Testing and Balance

各系统功能测试及运行，测量其性能
Building system functional testing

各系统控制策略
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系统整体运行
Whole building commissioning

设备及系统操作维护人员培训
Equipment and system operation training

后期系统运行效果回访
Performance review



调适是“整合”技能的代表

空调

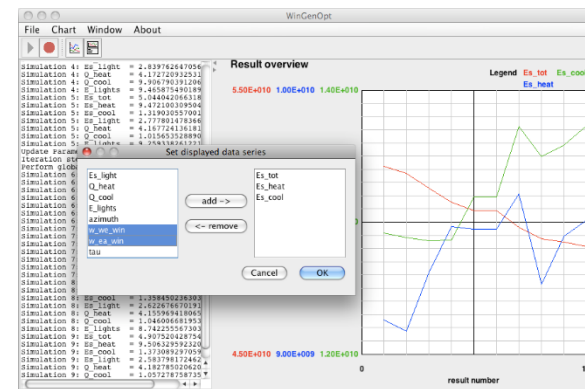
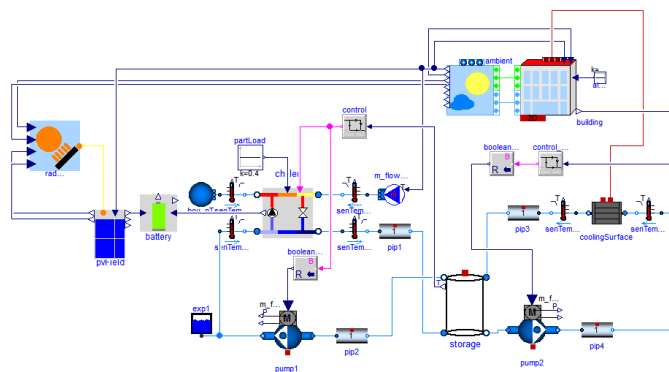
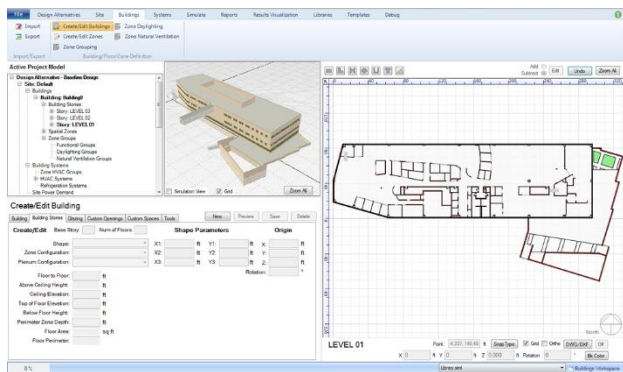


自控

理论



实践





调适是高科技么?

30:70

INSTALLATION CHECK SHEET – CHILLER										Page 1 of 3
PROJECT:		AVON R&D Center		COMPONENT:		CHILLER				
LOCATION:		Shanghai		TAG:		DISCIPLINE: HVAC				
Ensure that all safety procedures are followed while completing this form. If a conflict exists between the installation check sheet and current construction documents, the construction documents will take precedence over the installation check sheet.										
RESULT		INITIAL		DATE		NOTE				
- Equipment data (compare nameplate data with approved submittal)										
a) Service Space:		Location:								
b) Brand:		Model:								
c) SI #:										
d) Cooling capacity:		kW								
Chilled water flow:		m ³ / h		Cooling water flow:		m ³ / h				
Supply fan power:		KW		RPM						
e) Electrical System:		220 V, 2 Phase, 50 Hz								
- Installation										
1) Casing condition good: no dents, leaks, door gaskets installed.		Y		N		NA				
2) The unit interior is clean and free of all shipping material. Vibration isolation bolts loosened.		Y		N		NA				
3) Clean up of equipment completed per contract documents.		Y		N		NA				
4) The Chiller is free of visual damage.		Y		N		NA				
5) Compressor, liquid and suction line service valves open.		Y		N		NA				
6) Moisture indicator shows no moisture.		Y		N		NA				
7) Correct oil level (check sight glass during operation, if available).		Y		N		NA				
8) Crankcase heater (if applicable) energized long enough for startup.		Y		N		NA				
9) The unit is equipped with VFD for the supply.		Y		N		NA				
10) The flow direction is correct.		Y		N		NA				
11) A modulate control valve is provided for the heating/cooling coil.		Y		N		NA				
12) All components, bolts, fixings, tie bars etc., are secured.		Y		N		NA				
13) The lubricant is fresh and of the correct grade.		Y		N		NA				
14) There is a minimum of clear space in front of the control panels for operator daily maintenance.		Y		N		NA				
15) Enough maintenance space is provided for coil cleaning.		Y		N		NA				
16) The unit is installed on a housekeeping pad.		Y		N		NA				
17) Vibration isolators are installed.		Y		N		NA				
18) Flexible connections are installed between the chiller and pipe.		Y		N		NA				
19) Piping is insulated per specifications with proper jacketing and fitting covers.		Y		N		NA				
20) Piping has labeling and valve ID tags.		Y		N		NA				
21) Power disconnects in place and labeled.		Y		N		NA				
22) Diameter of wire is according to the requirement of chiller max. power.		Y		N		NA				
23) All electric connections tight.		Y		N		NA				

No.	Location			Tag / ID		Description	Qty.	Prior
	Part of Building	Level	Area	Type	ID			
1	Basement	B2	Hotwaterpumproom	HWP	HWP-B-B2-01	Heating Water Pump	1	5
2	Basement	B2	Hotwaterpumproom	HWP	HWP-B-B2-02	Heating Water Pump	1	5
3	Basement	B2	Hotwaterpumproom	HWP	HWP-B-B2-03	Heating Water Pump	1	5
4	Basement	B2	Hotwaterpumproom	HWP	HWP-B-B2-04	Heating Water Pump	1	5
5	Basement	B2	Hotwaterpumproom	HWP	HWP-B-B2-05	Heating Water Pump	1	5
6	Basement	B2	Hotwaterpumproom	HWP	HWP-B-B2-06	Heating Water Pump	1	5
7	Basement	B2	Hotwaterpumproom	HWP	HWP-B-B2-07	Heating Water Pump	1	5
8	Basement	B2	Hotwaterpumproom	HWP	HWP-B-B2-08	Heating Water Pump	1	5
9	Basement	B2	Hotwaterpumproom	HWP	HWP-B-B2-09	Heating Water Pump	1	5
10	Basement	B1	A	CT	CT-B-B1-05	Cooling Tower	1	20
11	Basement	B1	A	CT	CT-B-B1-05	Cooling Tower (Spare)	1	20
12	Basement	B4	C	CH	CH-B-B4-01	Central Chiller	1	50
13	Basement	B4	C	CH	CH-B-B4-02	Central Chiller	1	50
14	Basement	B4	C	CH	CH-B-B4-03	Central Chiller	1	50
15	Basement	B4	C	CH	CH-B-B4-04	Central Chiller	1	50
16	Basement	B4	C	CH	CH-B-B4-05	Central Chiller	1	50
17	Basement	B4	C	CH	CH-B-B4-07	Geothermal HP unit	1	20
18	Basement	B4	C	CH	CH-B-B4-08	Geothermal HP unit	1	20
19	Basement	B4	C	CHWP	CHWP-B-B4-01	Chilled Water Pump - Chiller	1	10
20	Basement	B4	C	CHWP	CHWP-B-B4-02	Chilled Water Pump - Chiller	1	10
21	Basement	B4	C	CHWP	CHWP-B-B4-03	Chilled Water Pump - Chiller	1	10
22	Basement	B4	C	CHWP	CHWP-B-B4-04	Chilled Water Pump - Chiller	1	10
23	Basement	B4	C	CHWP	CHWP-B-B4-04a	Chilled Water Pump - Chiller	1	10
24	Basement	B4	C	CHWP	CHWP-B-B4-04b	Chilled Water Pump - Chiller	1	10
25	Basement	B4	C	CHWP	CHWP-B-B4-05	Chilled Water Pump - Buffer	1	10
26	Basement	B4	C	CHWP	CHWP-B-B4-06	Chilled Water Pump - Buffer	1	10
27	Basement	B4	C	CHWP	CHWP-B-B4-07	Chilled Water Pump - Buffer	1	10
28	Basement	B4	C	CHWP	CHWP-B-B4-08	Chilled Water Pump - Buffer	1	10
29	Basement	B4	C	CHWP	CHWP-B-B4-09	Chilled Water Pump - Buffer	1	10
30	Basement	B4	C	CHWP	CHWP-B-B4-09a	Chilled Water Pump - Buffer	1	10
31	Basement	B4	C	CHWP	CHWP-B-B4-09b	Chilled Water Pump - Buffer	1	10
32	Basement	B4	C	CHWP	CHWP-B-B4-10	Chilled Water Pump - East Comm.	1	20
33	Basement	B4	C	CHWP	CHWP-B-B4-11	Chilled Water Pump - East Comm.	1	20
34	Basement	B4	C	CHWP	CHWP-B-B4-11a	Chilled Water Pump - East Comm.	1	20
35	Basement	B4	C	CHWP	CHWP-B-B4-12	Chilled Water Pump - West Comm.	1	20
36	Basement	B4	C	CHWP	CHWP-B-B4-13	Chilled Water Pump - West Comm.	1	20



调适是高科技么？

30:70

某智慧园区办公楼冬季热舒适性调适 务实的工作计划和日常小结

日期	工作内容	调适过程与数据记录
1207	现场检查设备运行状况	1. 检查各区域温度； 2. 检查各区域湿度； 3. 检查各区域新风量； 4. 检查各区域CO2浓度。
1208	水力平衡调试及系统检查	1. 检查水力平衡调试情况； 2. 检查系统运行状况； 3. 检查系统压力； 4. 检查系统流量。
1209	1208-1210	1. 检查水力平衡调试情况； 2. 检查系统运行状况； 3. 检查系统压力； 4. 检查系统流量。
1211-1218	1211-1218	1. 检查水力平衡调试情况； 2. 检查系统运行状况； 3. 检查系统压力； 4. 检查系统流量。



某智慧园区办公楼冬季热舒适性调适 应急方案及处理

应急处理

故障处理

故障描述：水力平衡调试中，3号楼3F空调机组的回水阀门关闭，回水流量无法再次提升，其回水温度正常。

- 故障处理：
 - 第1步：检查3F空调机组的回水阀门是否关闭；
 - 第2步：检查3F空调机组的回水温度是否正常；
 - 第3步：检查3F空调机组的回水流量是否正常；
 - 第4步：检查3F空调机组的回水压力是否正常；
 - 第5步：检查3F空调机组的回水水质是否正常；
 - 第6步：检查3F空调机组的回水管道是否堵塞；
 - 第7步：检查3F空调机组的回水系统是否正常。

应急处理

故障处理



应急处理

故障处理

故障描述：水力平衡调试中，3号楼3F空调机组的回水阀门关闭，回水流量无法再次提升，其回水温度正常。

- 故障处理：
 - 第1步：检查3F空调机组的回水阀门是否关闭；
 - 第2步：检查3F空调机组的回水温度是否正常；
 - 第3步：检查3F空调机组的回水流量是否正常；
 - 第4步：检查3F空调机组的回水压力是否正常；
 - 第5步：检查3F空调机组的回水水质是否正常；
 - 第6步：检查3F空调机组的回水管道是否堵塞；
 - 第7步：检查3F空调机组的回水系统是否正常。

应急处理

故障处理





调适也可以是“高大上”的

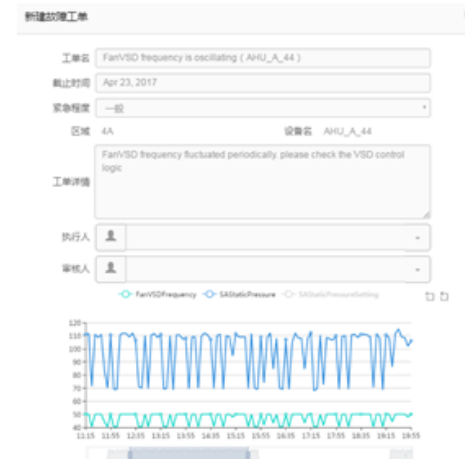
上海丰调 上海久维

嵌入人工智能的能效管理平台

Building Energy Platform with AI



人工智能自动故障诊断: AHU变频风机频率震荡



- AHU风机变频器控制故障。
- 风速、风压及AHU风机转速周期性震荡。
- 采用时序分析算法。

AHU风机转速周期性震荡除了缩短变频器的寿命之外, 还会影响租户的舒适性 (温度波动、送风量波动、噪声等)

上海丰调节能技术有限公司 上海久维建筑科技有限公司

人工智能自动故障诊断: AHU 风机控制故障



- 控制点与状态不一致: AHU风机开启但其变频器频率为零。
- 送风静压为 178.5Pa, 远高于设定点 80Pa, 造成了大量风机能耗浪费。
- 能源浪费: 63,273 kWh/年/台。

能源浪费估算考虑了风机控制静压设定点。

上海丰调节能技术有限公司 上海久维建筑科技有限公司



感想 Further Thoughts



也是苦活、累活，是磨难！

应急处理

现场照片



末端漏水点



锅炉房地暖泵



方案1：管道快修胶带



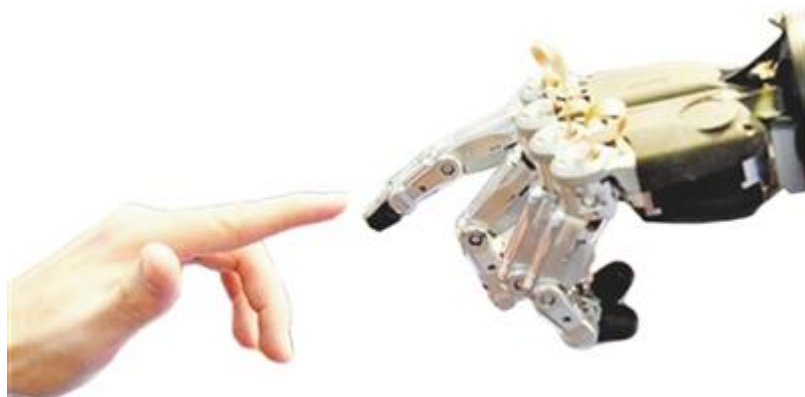
方案2：管夹



方案3：更换管路



也有快乐的时候...



建筑智慧能源整体解决方案 Building Smart Energy Solution



Thanks!

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中美清洁能源绿色金融高级顾问
生态环保基金战略合伙人
上海市特聘绿色建筑专家
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LEED AP BD+C

Senior Advisor for Green Finance, CERC-BEE, US&CN
Strategic Partner, Eco Fund
Shanghai Distinguished Green Building Expert
Tongji Distinguished Green Building Mentor
LEED BD&C Senior Expert