BUILDINGS ENERGY EFFICIENCY CONSORTIUM

U.S. - CHINA CLEAN ENERGY RESEARCH CENTER (CERC-BEE)

YEAR 4 JOINT ANNUAL MEETING
Berkeley California

B-3 Cool Roofs & Urban Heat Islands 冷屋顶与城市热岛效应

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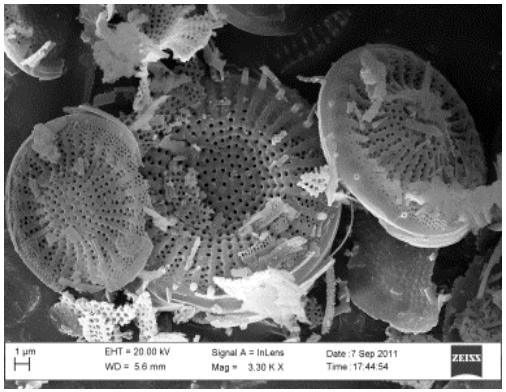
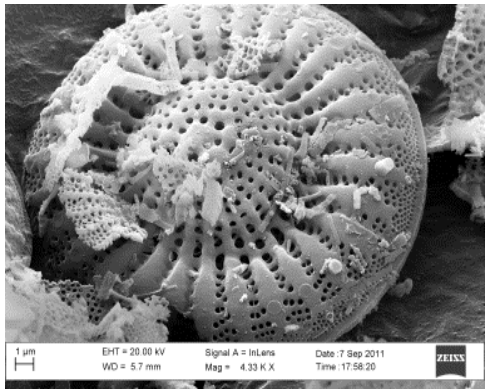
Presented By

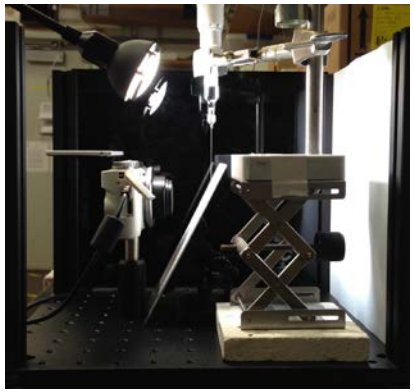
Lawrence Berkeley National Laboratory,
Oak Ridge National Laboratory, and Dow Chemical

August 25, 2014

SECTION 1:
ANTI-SOILING COATINGS
第一节：抗污蚀涂层







Purpose and objective
目标

Problem Statement存在问题

- White cool roof coatings save AC, but soiling reduces their performance (reflectance) 白色屋顶涂层能减少空调用量，但污蚀降低了它的作用 (反射率)
- Goal is to demonstrate that super-hydrophobic powders can be added as anti-soiling agents to environmentally friendly, acrylic-based cool roof coating 目的是展示超抑水粉末能充当防腐介质被加入到环保丙烯酸系节能屋顶涂层中

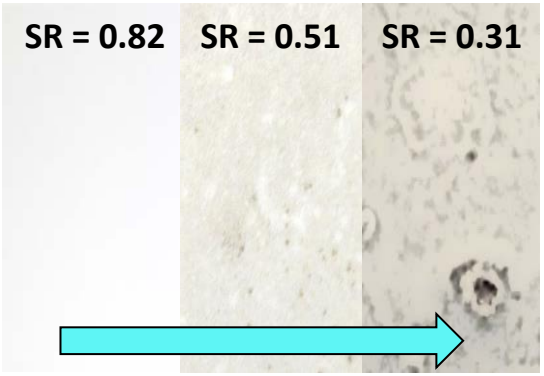
Project Objectives 项目目标

- Maintain high reflectance and integrity over prolonged exposures (> 10 years) 维持长期的高反射率和完整性 (大于10年)
- Double energy savings of acrylic cool roof coatings over service life 使丙烯酸系节能屋顶涂层的节能量加倍
- Demonstrate these coatings in key buildings and facilities in the US and China 将这些涂层运用到一些中国和美国关键的建筑和设施中

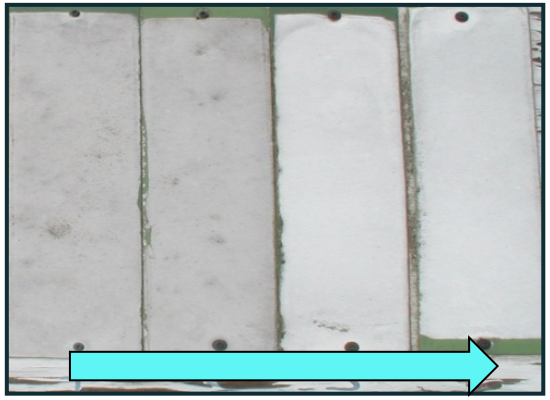
Anti-Soiling Coating Development (ORNL, Dow Chemical)
抗污蚀涂层研发（ORNL, 陶氏化学）

Hydrophobicity can improve soiling resistance, coating life
抑水性可提高耐污染度，以及涂层寿命

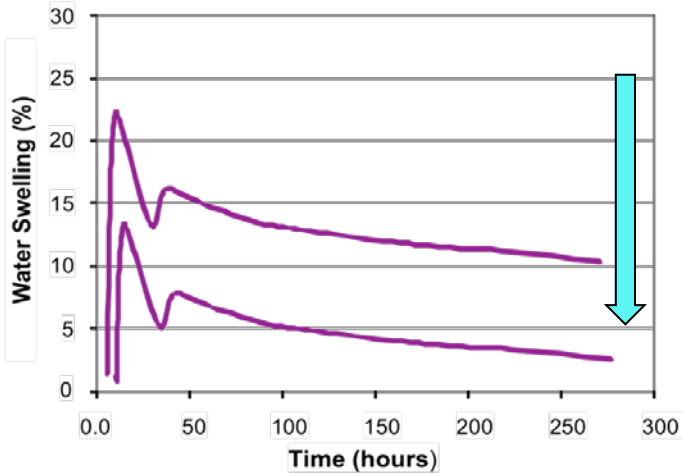
(1) Solar reflectance (SR) decreases over time due to soiling and microbial growth
由于污染和微生物的生长，太阳能反射率（SR）随着时间的推移减少



(2) Increasing hydrophobicity improves resistance to soiling
增加抑水性可以提高耐腐蚀度



(3) Increasing hydrophobicity can also reduce water swelling and coating permeability, improving roof coating life
增加抑水性还可以减少吸水膨胀和涂层的渗透，提高屋顶涂层寿命

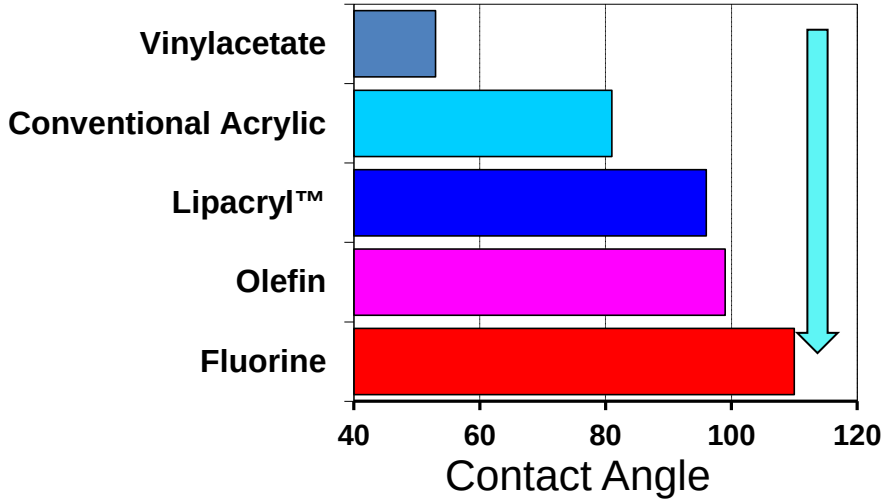


Additives can boost hydrophobicity
添加剂可以大幅提高抑水性

Solution to the coating soiling problem:

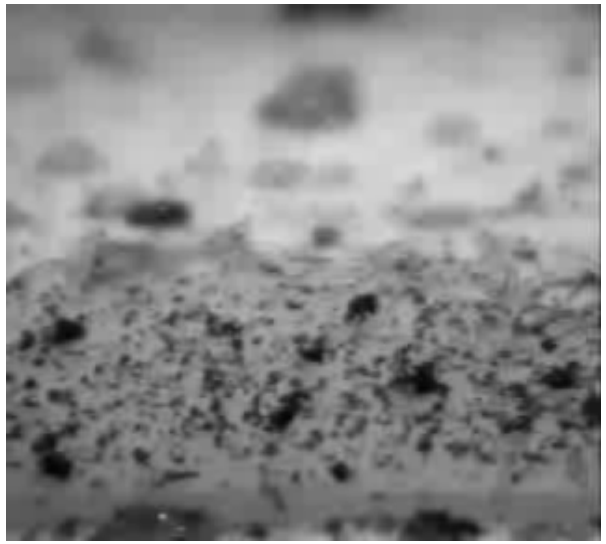
涂料腐蚀问题的解决方法：

Superhydrophobic additives increase resistance to water, soiling and microbial growth
超抑水性添加剂提高的耐水性，防止腐蚀和微生物的生长

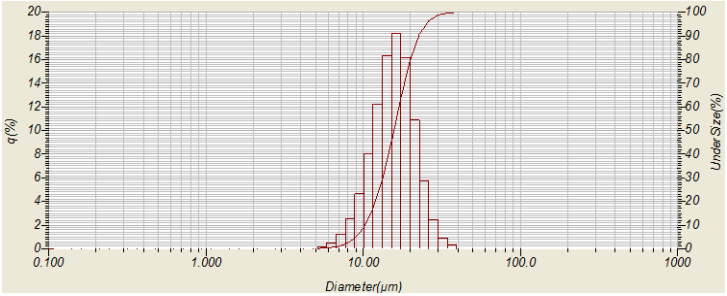


Acrylic chemistry can increase hydrophobicity but not completely solve soiling and water permeation problems
丙烯酸类化学材料可以增加抑水性，但不能完全解决腐蚀和水渗透的问题

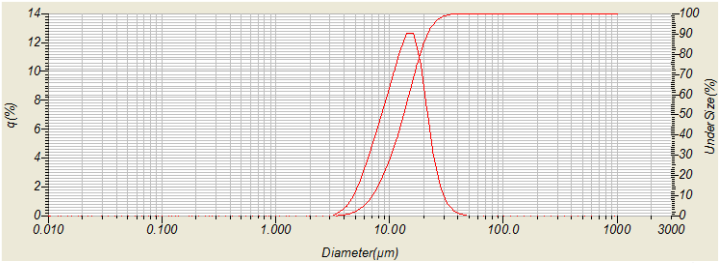
Dirt, dust and biological organisms do not stick to superhydrophobic surfaces
污垢，灰尘和生物有机体无法附着于超抑水表面



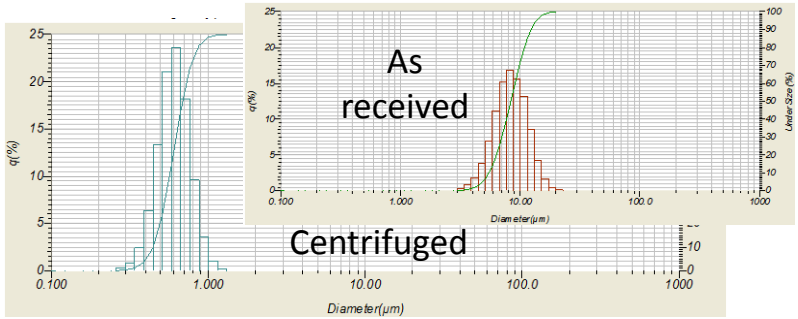
ORNL provided superhydrophobic powders to Dow Chemical
橡树岭国家实验室提供了超抑水性粉体给陶氏化学



Celtix (mean size 16.2 μm) 平均尺寸16.2 μm



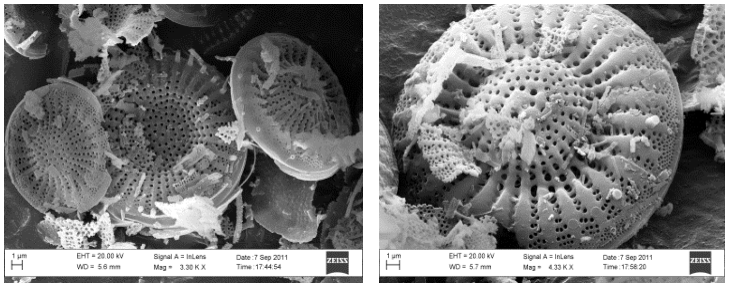
Diafil (mean size 14.0 μm)平均尺寸14.0 μm



Fumed silica (mean size 8.4 μm as received, 0.60 μm centrifuged)平均尺寸8.4 μm、离心后0.60 μm

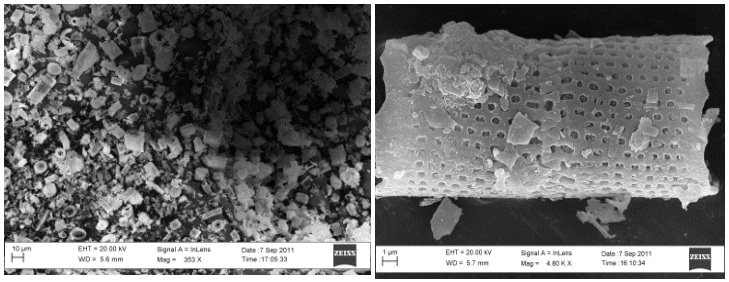
Celtix diatomaceous earth

Celtix硅藻土



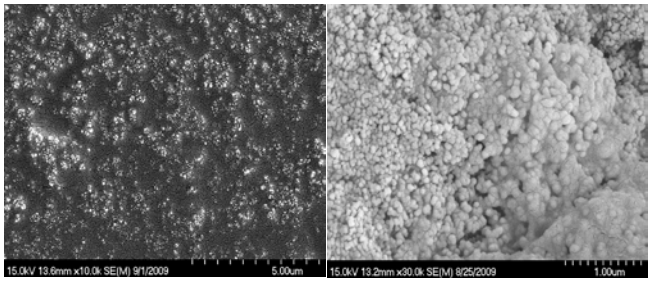
Diafil diatomaceous earth

Diafil硅藻土



Fumed nanosilica (agglomerated)

煅制纳米二氧化硅 (凝聚)

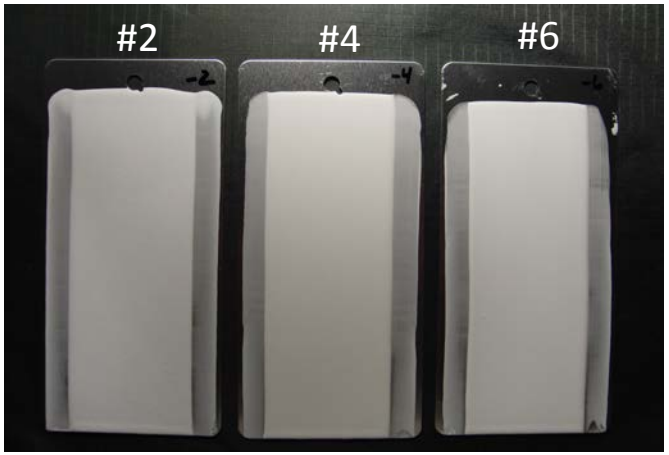


Dispersing SH powders in latex
在乳胶中加入SH粉

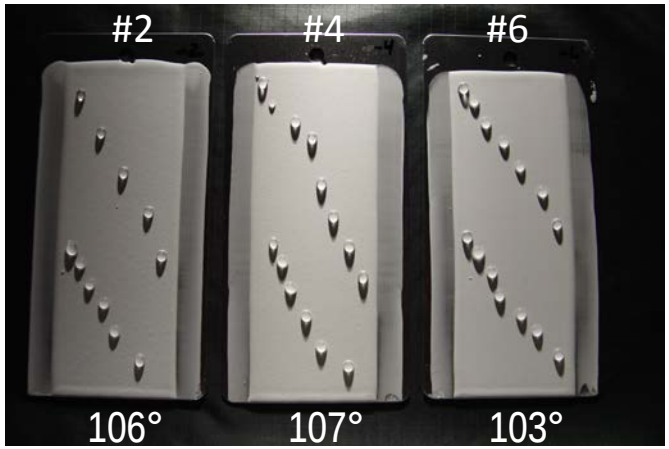
- Celtix-$C_8H_4F_{13}$ fluorinated silane diatomaceous earth was successfully dispersed at low levels into water-based roof coating using the dispersant Tamol and high shear dispersator.
  Celtix-$C_8H_4F_{13}$氟化硅烷硅藻土使用分散剂Tamol和高强分散器后成功地分散加入到水基屋顶涂料中。
- Celtix-$C_{18}H_{37}$ alkyl silane DE was not easily dispersible. Grit and phase separation was observed possibly due to the large, long chain hydrophobic groups on the DE surface.
  Celtix-$C_{18}H_{37}$ 烷基硅烷 DE 不容易分散。观察到的砂砾和相分离可能是由于大的，长链抑水性对在DE表面上。
- Diafil fillers, both modified and unmodified, could be incorporated into the roof coating formulation at levels up to 5% volume substitution.
  改良和未改良的Diafil填充剂，可以以最多5%的量结合到屋顶涂料配方中。
- The unmodified and fluoro-silane modified variants could be incorporated at levels up to 25% volume substitution.
  可以加入最多25%的未改良的和氟硅烷改良的变体。

Fluoro-functionalized silica (SiO_2) and diatomaceous earth (DE) were incorporated in a standard latex formulation 氟功能化的二氧化硅（SiO_2）和硅藻土（DE）被加入到一个标准的胶乳配方中

SiO_2 DE Control 控制



SiO_2 DE Control控制



water contact angle

水的接触角

- Silica particles well dispersed in latex coatings
  二氧化硅粒子很好地分散在乳胶涂料中
- No change in coating color with up to 2% silica by weight
  加入了高达2％的二氧化硅后涂料颜色没有变化

- Very slight increase in hydrophobicity with the silica incorporated coatings
  在掺入二氧化硅后，涂层的抑水性增加的非常轻微
- **Silica particles did not penetrate the surface**
  二氧化硅粒子未穿透表面

To increase coating hydrophobicity, the silica particles must be exposed at the surface
为增加涂层的抑水性，二氧化硅颗粒必须暴露在表面

Coating performance
涂层性能

Dirt resistance 耐沾污性

- Dirt resistance of the EC1791 reference acrylic coating is unaffected by the presence of the superhydrophobic silica particles
  丙烯酸类涂料EC1791的耐粘污性不受超抑水性二氧化硅粒子存在的影响

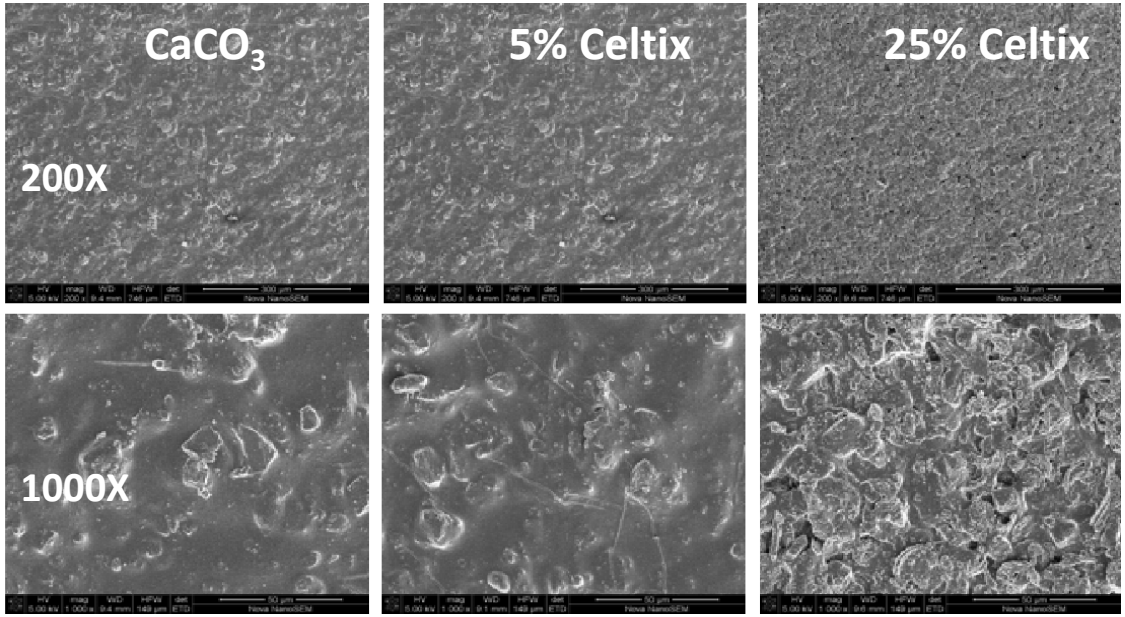
Film Strength 强度

- Elongation at break values were dependant on extender: Celtix > Celtix-$C_8H_4F_{13}$ > Celtix-$C_{18}H_{37}$
  断裂伸长率依赖于填充剂: Celtix > Celtix-$C_8H_4F_{13}$ > Celtix-$C_{18}H_{37}$
- All samples showed elongation at break values of >100% and thus passed ASTM D6083 standard
  所有样品显示出断裂伸长率>100％，从而通过ASTM D6083标准

Water Permeability 透水性

- Water Induced Swelling: All films that contained unmodified Celtix or SH powders showed higher water pickup @ 29 days than the 1791/ARM91-1 reference latex coating
  水引起膨胀：在第29天所有薄膜包含未修改的Celtix或SH粉比1791/ ARM91-1参考乳胶涂料具有更高的水收集率
- The swelling ratios @ 29 days of three Celtix appeared to increase as the substitution level increased
  因为替代程度增加，三个Celtix的溶胀率在29天增加

SEM images of film surfaces
膜表面的SEM图像



2D 2A 5A

- The samples containing the $CaCO_3$ control and the 5% Celtix are very similar
  含有碳酸钙的样品和5％的Celtix样品非常相似
- The 25% Celtix coating has a considerably rougher surface than those containing less filler
  含25％的Celtix的涂层比那些含有较少量Celtix的涂层有着更粗糙的表面
- In all cases the Celtix appears coated in resin and the surface functionality is not effective
  在Celtix涂在树脂的所有情况下，表面功能都无效

Anti-Soiling Coating Testing (LBNL)
抗污蚀涂层测试 (LBNL)

LBNL will use its accelerated aging method…
LBNL将用其加速老化方法…

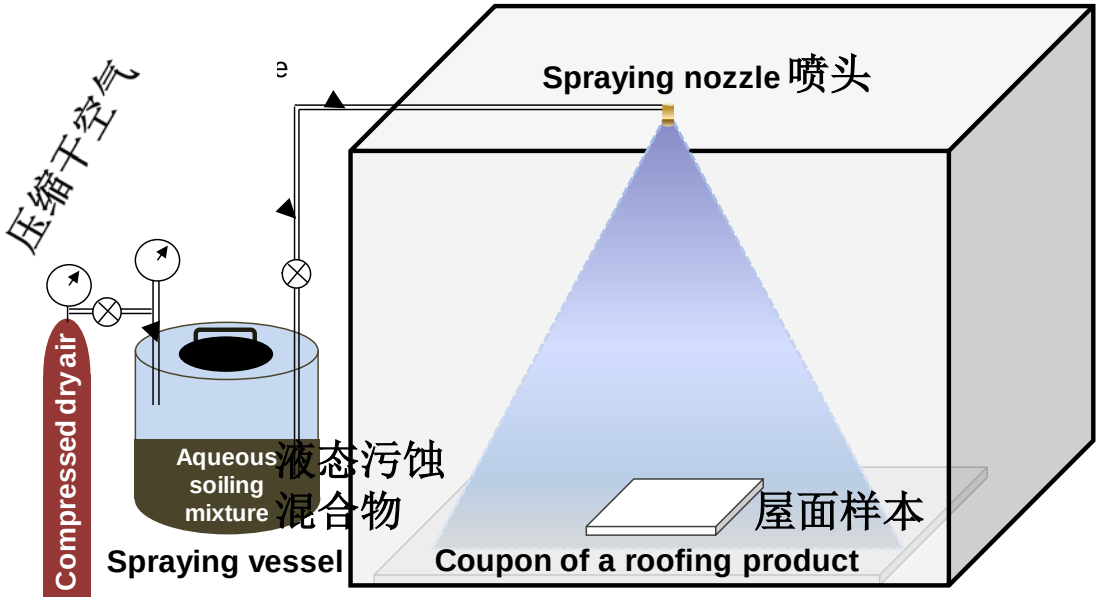
Accelerated soiling 加速污蚀
(atmospheric deposition 大气沉积物)

尘

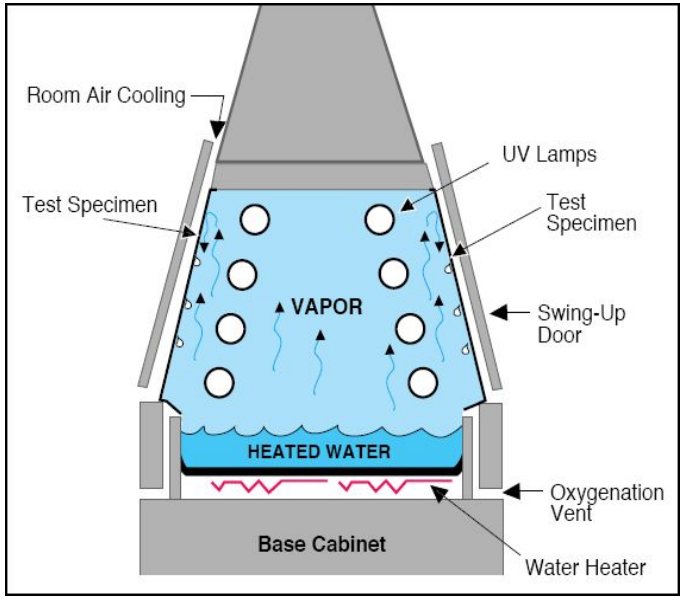
盐

有机物

煤烟



Accelerated weathering 加速老化
(UV, heat, moisture 紫外线、热、潮)

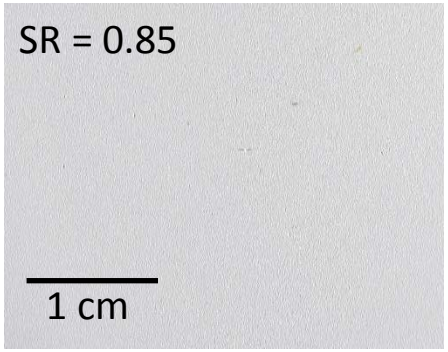


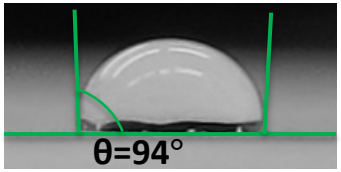
Sleiman et al. (2014) *Solar Energy Materials and Solar Cells*

…to evaluate reflectance and contact angle changes as SH coatings age 来评估反射率，接触角度随常规涂层老化而变化

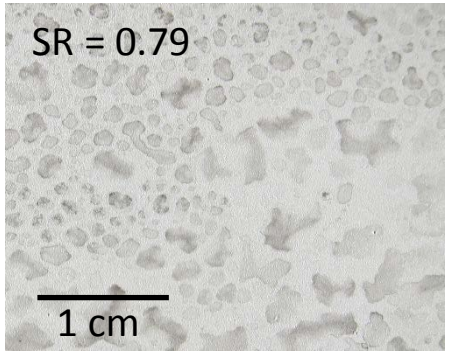
Conventional coating (not superhydrophobic)
常规涂层（非具超抑水性）

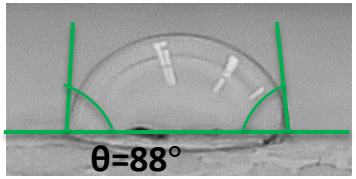
Initial
初始



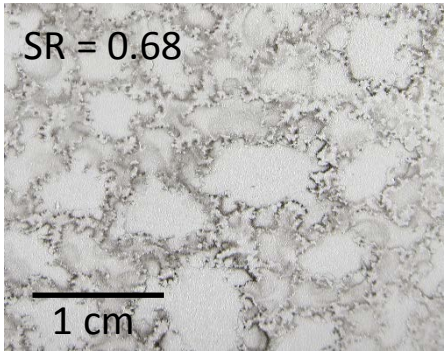


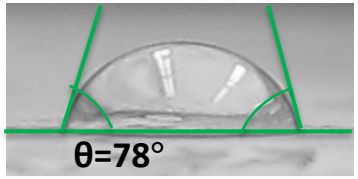
Simulated 3 years of exposure
模拟3年曝晒



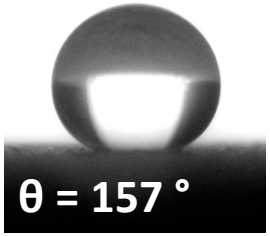


Simulated 5 years of exposure
模拟5年曝晒



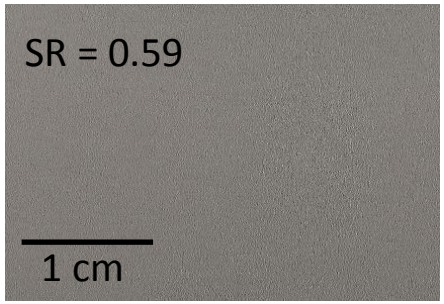


Superhydrophobic coating?… 具超抑水性的涂层？

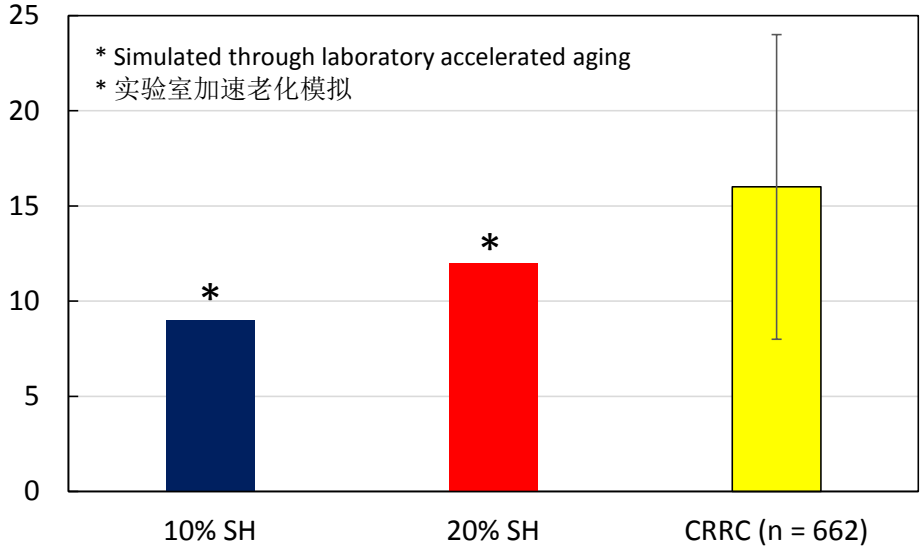


LBNL ran preliminary tests on ORNL samples
LBNL对ORNL的样品做了初步测试

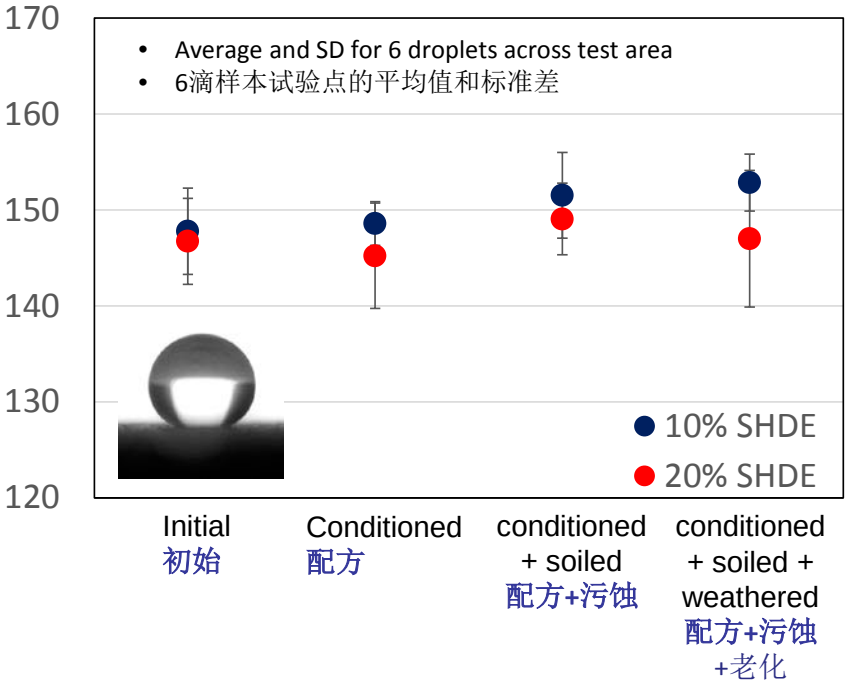
Epoxy coatings containing 10% and 20% superhydrophobic DE
含有10％和20％的超抑水性DE环氧涂料



Mean fractional loss of solar reflectance after three years of exposure (%)
经过三年的曝晒后，太阳反射率的平均下降比例 （％）

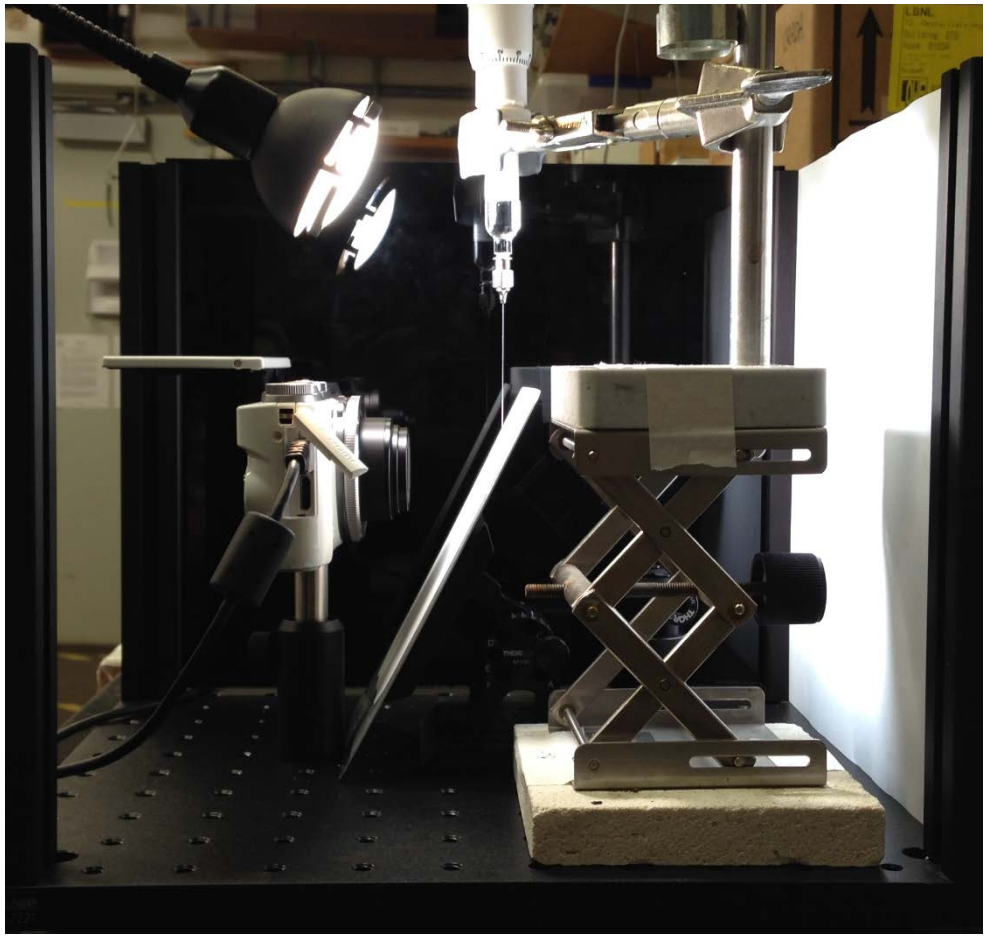


Water contact angle (^{o}) 水接触角度



Prototype resisted soiling and retained hydrophobicity
抗污蚀、保抑水性的原型样品

LBNL is building an apparatus to evaluate self-cleaning behavior LBNL正在搭建用于评估自洁性能的设备



Carbon black particles deposited on SH coating
沉积在超抑水性涂层的炭黑颗粒

Video recorded at 480 fps.
视频录制480fps

Key Year 4 technical achievements (i/ii)
关键的第4年的技术成果（I / II）

Accomplishments 成果

- Dow has found that the dispersability of ORNL SH Extenders into aqueous acrylic roof coatings can be achieved using dispersants and high shear mixing at levels as high as 25% substitution of the $CaCO_3$.
  陶氏化学发现，可以使用分散剂和高强混合把ORNL SH Extenders添加到水性丙烯酸屋顶涂料中以替代25％的$CaCO_3$
  - This was one of the main challenges of the project – dispersing water repellent powders in water based acrylic coatings

    这是该项目的主要挑战之一 – 把防水性粉末添加到水性丙烯酸涂料中

- Dow has observed a significant improvement in dirt resistance, a surface property, using fluorinated silane functionalization for the superhydrophobic particles embedded in the acrylic coatings, but increased water permeability is a problem that needs to be solved.
  陶氏化学发现，由于嵌在丙烯酸涂层的超抑水性颗粒有了含氟硅烷的作用，耐污染性有了显著改进，但水渗透性的增加是一个需要解决的问题。

Key Year 4 technical achievements (ii/ii)
关键的第4年的技术成果（II / II）

Accomplishments 成果

- ORNL has initiated anti biofouling studies using surface modified SH coatings that are expected to have enhanced anti biofouling properties
  橡树岭国家实验室已经开始使用表面经过修改的SH涂料的抗生物污染的研究，预计将有增强的抗生物污染性能

- 2 invention disclosures submitted (提交2项发明):
  - J. Simpson and G. Polyzos, “Superhydrophobic Coatings using Double Silane treated Silica Particles.”
  - S. Allman, M. Cheng, A. Desjarlais and D. Graham, “Art and Method on Accelerating Microbial Test of Materials.”

Schedule for completion of Year 4 Milestones
第四年里程碑时间表

- Schedule of completion for remaining (unmodified) Year 4 Milestones and Target Outcomes, percentage of cumulative unspent DOE funds
  完成剩余（未修改）的第4年里程碑和目标成果的时间表，累计未动用美国能源部的资金比例

Tasks	CY14 Q3	CY14 Q4	CY15 Q1	CY15 Q2	CY15 Q3	CY15 Q4
Complete first evaluation of acrylic formulation 完成丙烯酸配方的首次评测						
Complete anti-soiling coating development work 完成的防污涂料的开发工作						
Complete pigmented formulation development 完成着色配方的开发						
Complete accelerate microbial and soiling experiments 完成加速的微生物和污染实验						
Accelerated environmental coating tests complete 加速的环保涂料测试						

Scheduled task completion time 原计划完成时间

New scheduled completion time 新的计划完成时间

*The new completion times dependent on the availability of CY14 and CY15 funding
*新完成时间取决于CY14和CY15的资金

Issues/risks and abatement plans (i/ii)
问题/风险和对策 (I / II)

Issues and Risks

- Incorporation of the silica powders in the formulations to increase anti-soiling properties may change other desirable coating properties – e.g. durability, bonding, optical properties and coating permeability
- Different functionalized silica powders may not disperse in the polymer matrix as expected
- Incorporating a high loading of silica in the anti-soiling coating may adversely effect the durability of the coatings

问题和风险

- 为提高防污性能掺入配方中的二氧化硅粉末，可能改变其它所需的涂料性能 - 例如耐久性，粘合，光学性能和涂层的渗透性
- 不同功能的二氧化硅粉末可能不会在聚合物基质中如预期地分散
- 掺入高负载的二氧化硅中可能对涂层的耐久性产生不利影响

Issues/risks and abatement plans (ii/ii)
问题/风险和对策 (II / II)

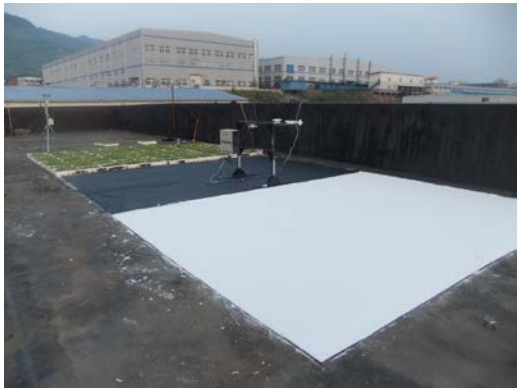
Abatement Plans

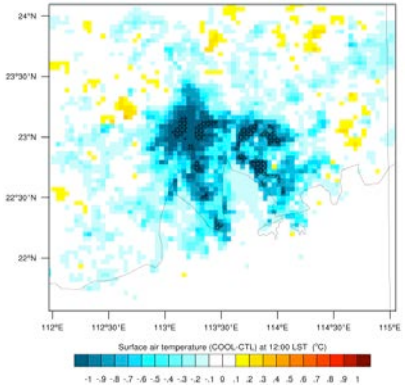
- Evaluate a range of different extenders with hydrophobic treatments
- Look at increased levels of hydrophobic treatment by modifying silica particle surface functionality, particle size and concentration
- Assess routes to moving more of the silica particle extenders to the film surface
- Assess route to minimizing the resin coating of the silica particles already at the film surface
- Perform accelerated and outdoor environmental evaluations of the proposed coating formulations to assess coating stability

对策

- 评估有抑水效果的 添加剂的范围
- 通过修饰二氧化硅粒子表面的功能，粒径和浓度以提高抑水效果
- 找到把更多的二氧化硅颗粒剂移至薄膜表面的方法
- 找到最小化的已在膜表面的二氧化硅颗粒的树脂涂层的方法
- 完成涂层的室外环境评估以评价涂层的稳定性

SECTION 2:
COOL ROOF INFRASTRUCTURE
第二节：冷屋顶基础设施

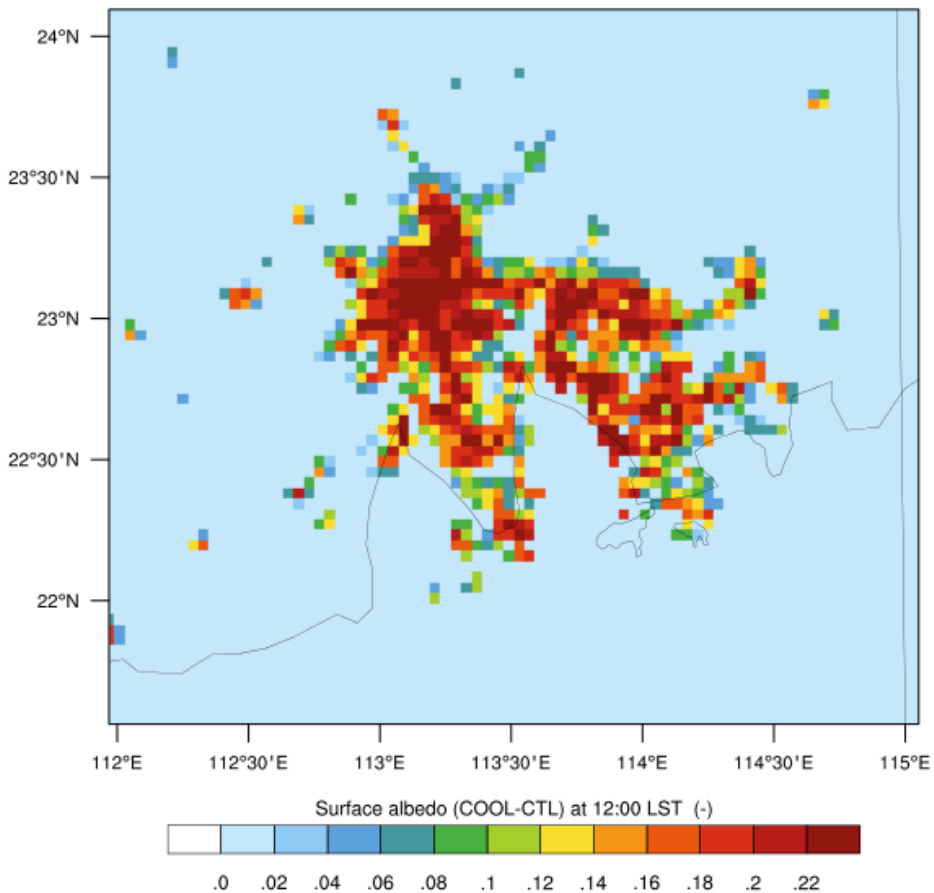




Climate Modeling
(LBNL, CAS)
气候模拟
（LBNL、中科院）

Cool roofs could significantly increase average urban albedo in Guangzhou (i/ii) 冷屋顶显著提高了广州地区的城市地表反照率

albedo increase
地表反照率的增加幅度



- Average *roof* albedo in Guangzhou could rise to 0.55 from 0.12

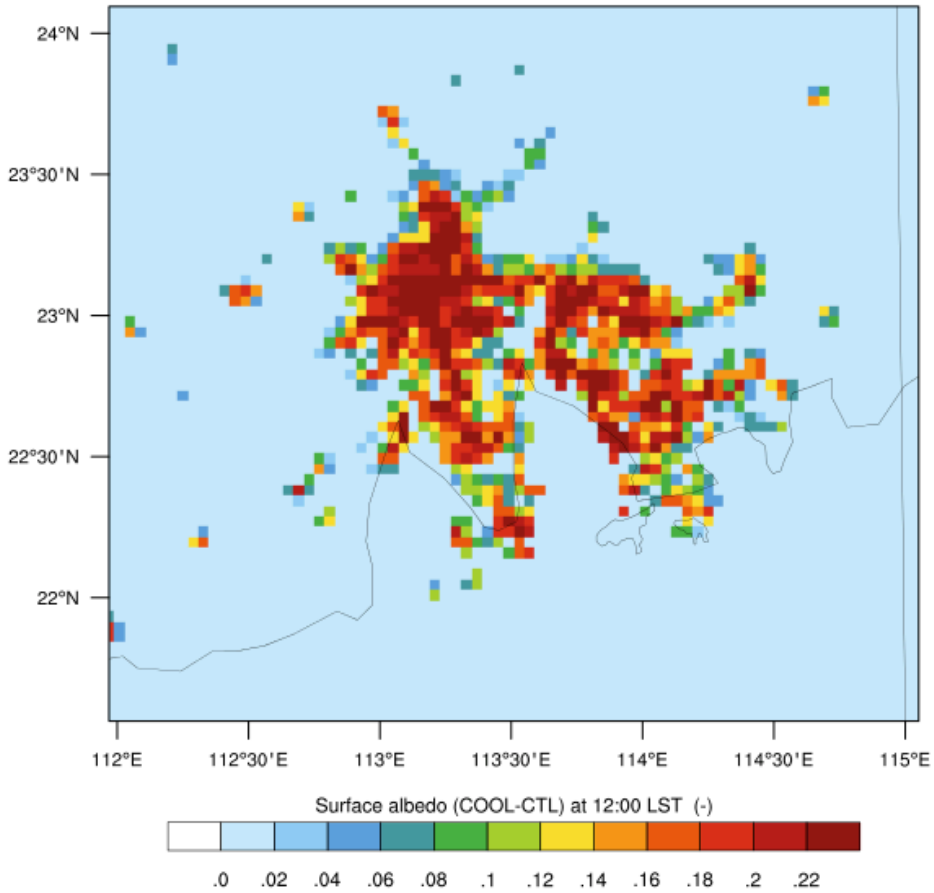
  广州城区*屋顶*反照率(反射率）平均值从0.12增至0.55

- This could increase the average *urban* albedo in downtown Guangzhou by as much as 0.22

  广州城区的*地表*反照率平均增加了0.22

Cool roofs could significantly increase average urban albedo in Guangzhou (ii/ii) 冷屋顶显著提高了广州地区的城市地表反照率

albedo increase
地表反照率的增加幅度



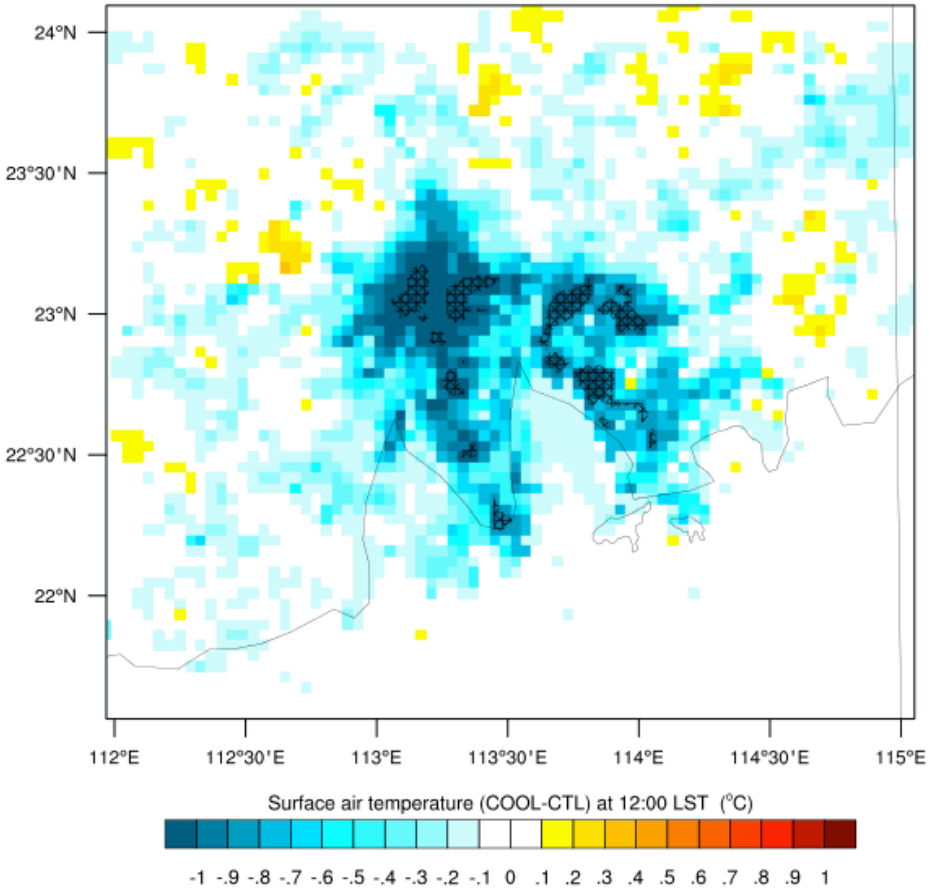
LBNL – IAP Collaboration
LBNL与IAP的国际合作

Meichun CAO, a scientist from the Institute of Atmospheric Physics (IAP) of the Chinese Academy of Sciences (CAS), visited Dev Millstein at LBNL for one month (May 2014)

曹美春，中国科学院大气物理研究所助理研究员，于2014年5月访问LBNL一个月，并与Dev Millstein就冷屋顶及其影响的数值模拟研究开展合作

Cool roofs could reduce summer air temperatures in Guangzhou by 1 °C 冷屋顶对夏季广州地区的降温可达1 °C

average temperature change
正午地面气温的变化



- Long term analysis improves understanding of cool roof effects across the cooling season
  模拟分析可加深理解冷屋顶在整个供冷季的效果
- 25 weeks modeled, sampled across the summers of 2004 – 2008
  2004-2008年夏季（5~9月）每月各取1周进行模拟，5年共模拟了25周
- Modeling included an additional 6 heat wave events for comparison
  还模拟了6个城市热浪发生期间的冷屋顶效果，作为与平均气象背景模拟试验的对比

Modeling work utilized the DOE's NERSC supercomputers
所有的数值模拟试验均是在DOE的NERSC超算平台上完成的

Next steps
下一步工作

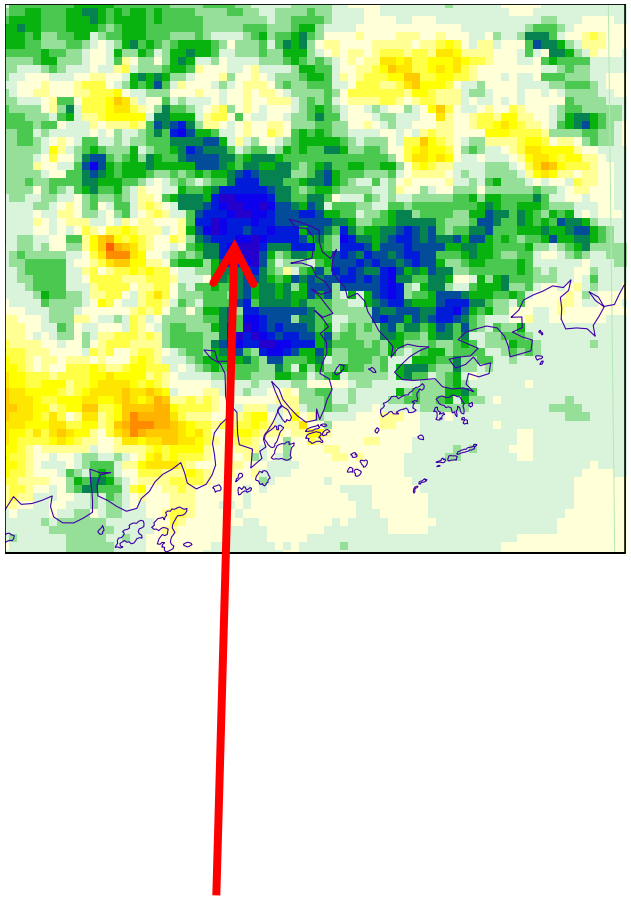
ΔT during heat waves?
城市热浪发生期间的降温作用？

- Do cool roofs produce different effects during heat waves compared to normal summer weeks?

  冷屋顶在正常夏日天气与发生城市热浪的天气条件下产生的降温效果是否不同？

- Initial modeling of an historic July 2004 heat wave indicates the possibility of larger temperature reductions

  对2004年7月一次城市热浪发生的初步模拟表明，冷屋顶起到的降温作用在热浪发生期间可能更显著



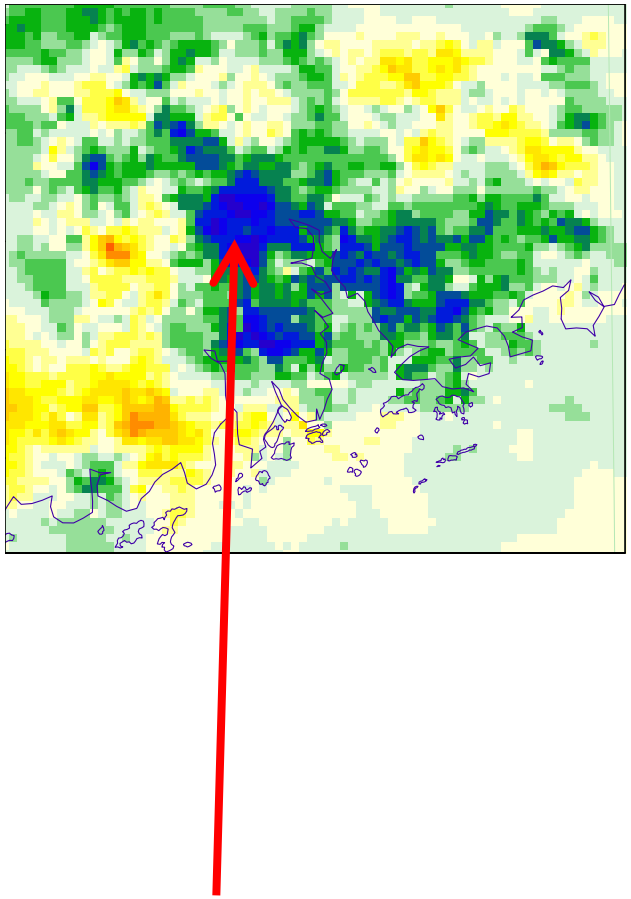
(1.5 °C temperature reduction)
(1.5 °C的降温幅度)

What we expect to learn by end of Year 4?
到第4年末，我们预期能得到哪些成果？

Expected products by end of CY 2014:
2014年的预期成果：

- Assessments of potential changes to weather induced by cool roofs in Guangzhou over the entire cooling season and during heat waves
  供冷季及发生城市热浪期间，冷屋顶对广州地区城市气象的影响
  - Urban air temperature reductions
    城市地面气温变化
  - Precipitation and wind speed changes
    降水量与风场变化

- Reduction to net atmospheric radiative forcing in Guangzhou (global cooling)
  广州地区地-气辐射收支变化（全球降温）

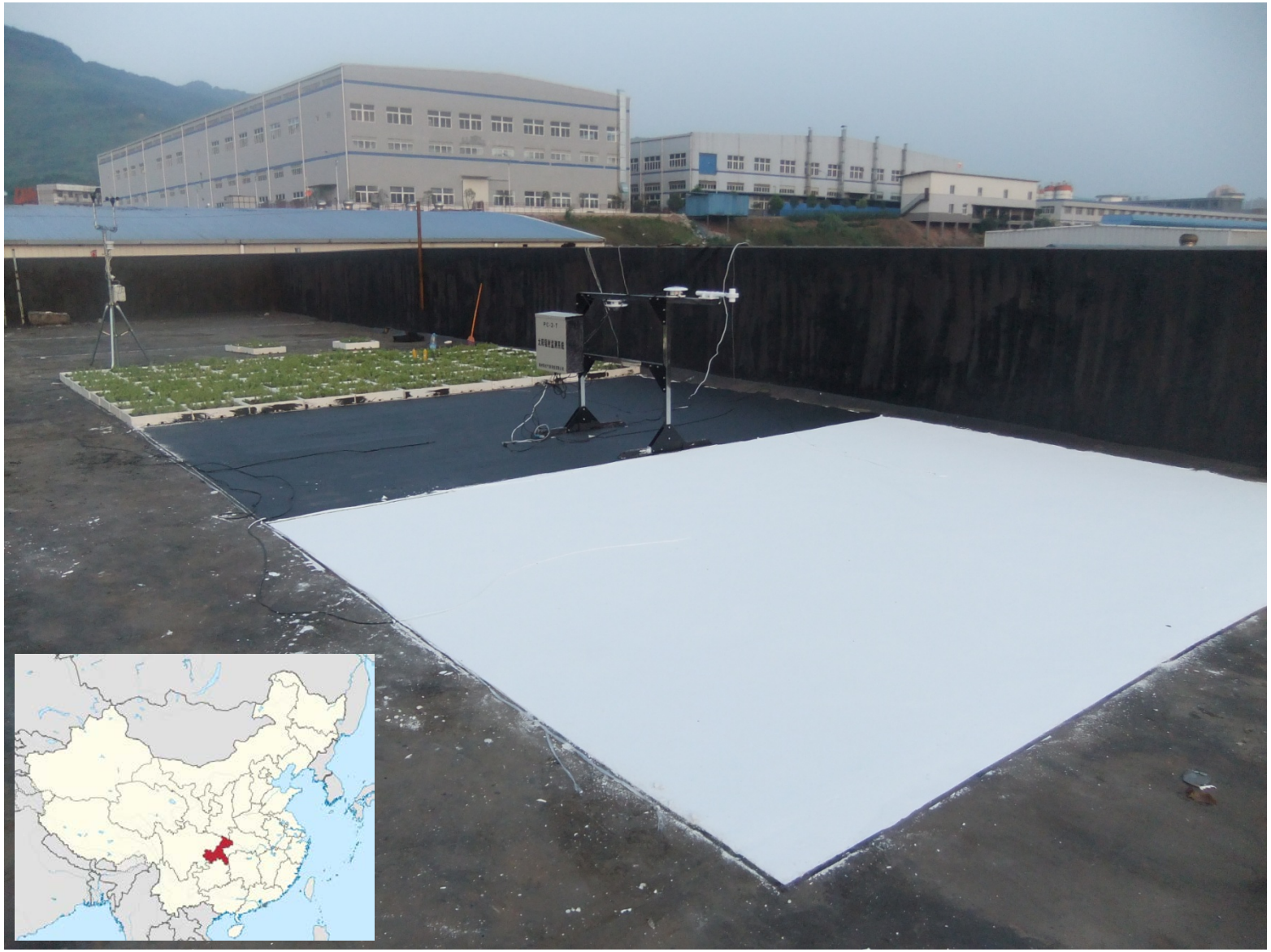


(1.5 °C temperature reduction)
(降温幅度1.5 °C)

Black, White, and Garden Roof Experiment in Chongqing (LBNL, CU)

在重庆进行的黑、白、种植面屋顶实验（LBNL、重庆大学）

Black/white/garden roof demonstration in Chongqing began this summer
在重庆市黑色屋面、白屋面和种植屋面示范实验（始于今夏）



Will measure annual energy savings from white roof, garden roof 白屋面与种植屋面全年节能测试

- Three adjacent rooms with black, white, garden roofs

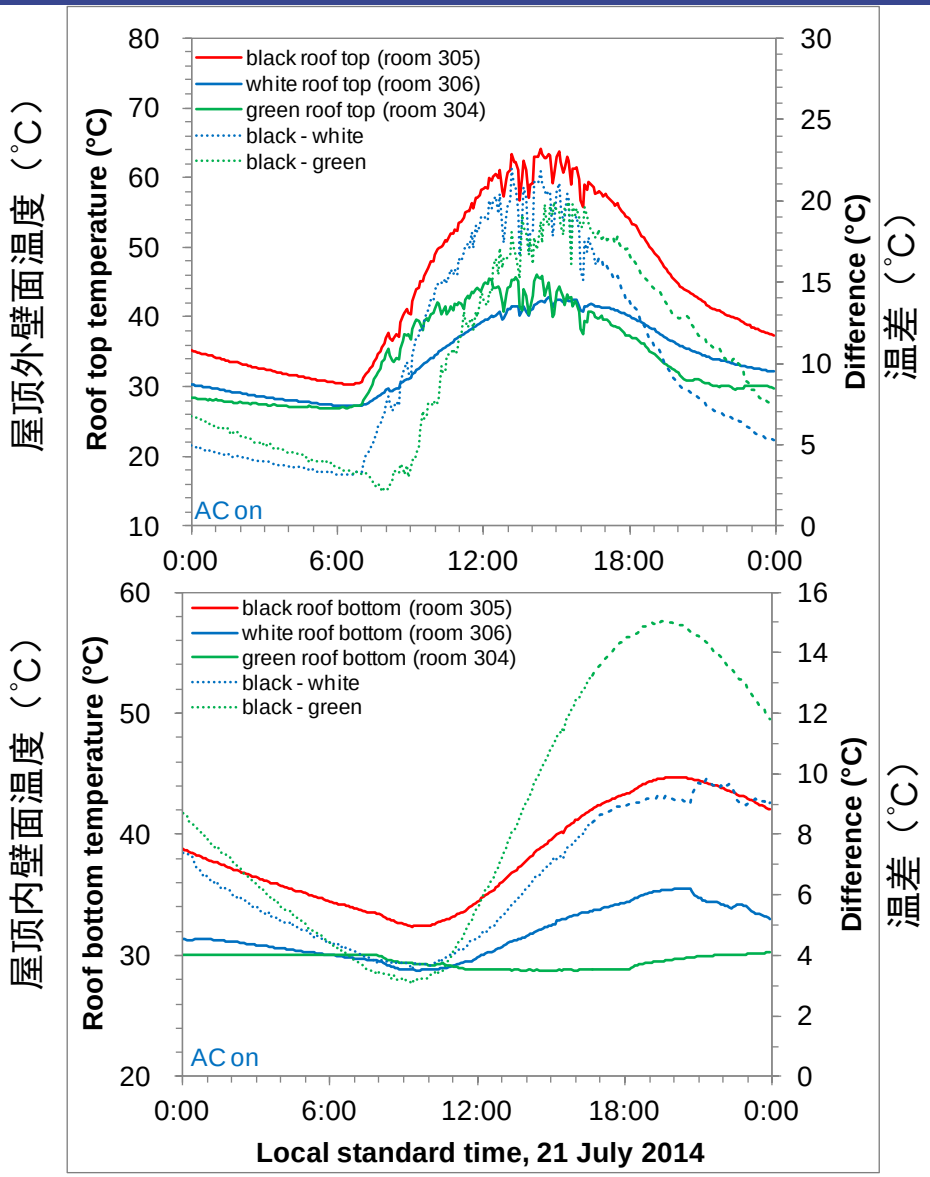
  三间相邻房间的屋面分别为黑色屋面、白色屋面和种植屋面

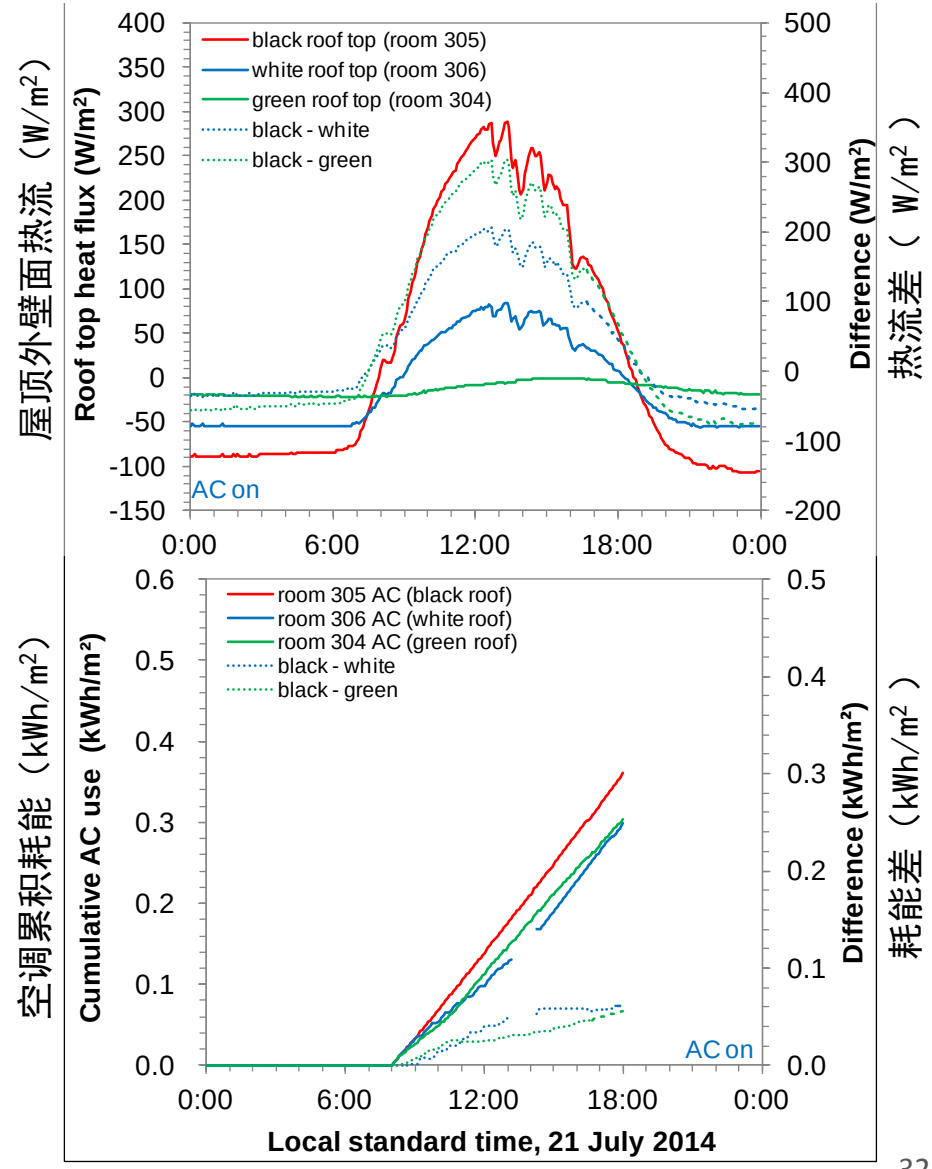
- Each room has own split system for heating, cooling 每间房间均有其单独的分体式风冷热泵空调器供热和供冷

- Measurements 测试参数:
  - roof top, roof bottom, indoor air temperatures 屋顶内、外壁面温度，室内空气温度
  - roof top heat flow 屋顶外壁面热流密度
  - HVAC energy use 空调器耗能
  - garden roof evapotranspiration, soil moisture 种植屋面蒸腾蒸发量，土壤湿度
  - weather 气象参数

- **Similar experiment planned for Guangzhou 在广州计划开展相似的实验**

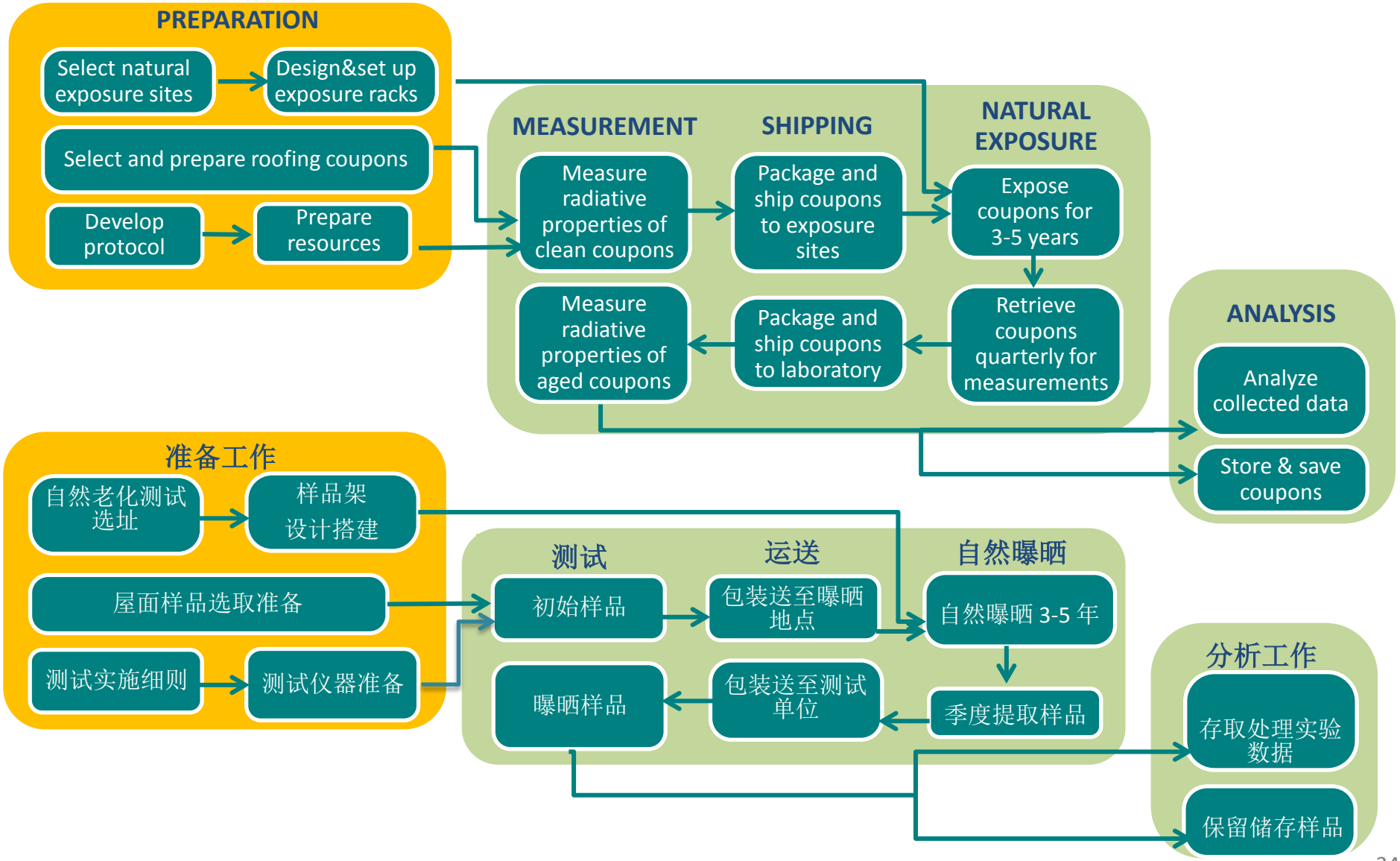
White roof, garden roof stay cooler, save energy
白屋面和种植屋面-有降温与节能效果





Natural Exposure Testing in China (MOHURD, GPABR, LBNL)
屋面材料的自然老化测试（由住建部、广东建研院、LBNL承担)

Natural exposure tests will assess soiling/weathering of roofing products in China 自然老化测试 - 将用来评估中国建筑屋面材料的污蚀老化



Project plan and time table
项目计划、进展时间段

- **Completed preparation for testing protocol, coupons, and exposure racks**
  团队已完成自然老化测试细则、样品及曝晒架设计等准备工作
- **Natural exposures start from September 1, 2014**
  样品自然曝晒自2014年9月1日起

2014.9-2017.9

- Quarterly retrieval & test for 3 years
- 每季度提取、测试样本; 连续测试三年

2017.9-2019.9

- Annual retrieval & test for 2 years
- 年度提取、测试样本; 连续测试两年

Natural exposure testing accomplishments
自然老化测试项目进展

- **MoHURD-RISN/GPABR - LBNL collaboration 住建部标准定额研究所、广东省建筑科学研究院、及伯克利国家实验室三方共同合作**
  - RISN-coordinated, GPABR-led multi-institute testing activities 住建部标准定额研究所负责协调实施计划、广东建研院担纲、及全国多家建筑科学研究院参加测试
  - LBNL provides technical assistance, reviews, and advice on protocols, planning, design, and testing of coupons伯克利国家实验室提供多方位技术指导
  - Two out of three RISN workshops held in Beijing and Nanjing (May, July) ; the third workshop scheduled in late August 第一、第二次工作会议分别在北京5月、南京7月召开; 第三次工作会议在8月底召开
- **Developed & distributed test protocol 制定完成屋顶材料老化测试方案、并由定额研究所传达公函及细则**
- **Selected testing sites, institutes, and industrial suppliers 确定参加测试地点、单位、及材料供应产家**

RISN-LBNL-GPABR Protocol meeting
三方会议讨论技术与计划

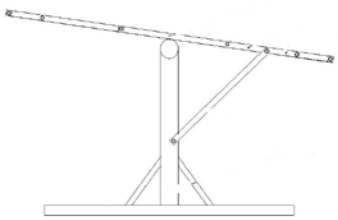
Site visit & selection (Lin Changqing of RISN Yang Shichao of GPABR in Shanghai)
选址现场考察（上海）

Completed design of coupon racks
完成样品曝晒架设计搭建

- **Completed coupon exposure rack designed for each site, similar to U.S. CRRC, but different tilt angles**
- **已完成样品曝晒架设计；样品测试倾斜角度均有别于美国的CRRC**
  - 2% tilt (~1°) for flat roof materials vs. CRRC tilt 5°

  平屋面2%倾斜率(倾斜角约1.15°) 而CRRC 倾斜角为5°
  - 20% tilt (~11°) for sloped roofing materials vs. CRRC tilt 45°

  坡屋面20%倾斜率(倾斜角约11.3°) 而CRRC倾斜角为45°



Have selected sites, institutes, industrial partners
已确定的测试地点、参加单位与工业伙伴

10 exposure sites
10个测试点

nine institutes
9家参测单位

- Xinjiang IBR 新疆建研院
- CABR 中国建研院
- CTC 中国建材检验认证集团
- Shanxi IBR 陕西建研院
- Jiangsu IBR 江苏建研院
- Sichuan IBR 四川建研院
- Xiamen IBR 厦门建研院
- GPABR 广东建研院
- Shenzhen IBR 深圳建研院

3 Chinese, 2 multinational industrial partners/suppliers 企业伙伴/材料供应商：3个中国公司、2个跨国公司

AkzoNobel 上海阿克苏	**Huarun Coating** 华东华润涂料	**Dow Chemical** 陶氏化学	**Chengguang** 江苏晨光涂料	**Nanshizixing** 中山南十字星

Key Year 4 technical achievements
第4年的关键技术成果

Accomplishments 技术成果

- Natural exposure testing program launched by LBNL, MoHURD RISN, 9 Chinese building research institutions, 3 Chinese/2 multinational roofing manufacturers initiates a Chinese roof rating program.

  由LBNL、住建部标准定额研究所、中国建筑科学研究院/广东省建研院等9家建研院、3家中国公司两 家屋面材料跨国公司参与的自然老化测试项目， 将为中国屋面材料的评级活动掀开序幕

- Black/white/garden roof experiment underway in Chongqing is the first four-season cool roof demonstration in China. 在重庆所进行的黑色屋面/白色屋面/种植屋面实验，是首例中国冷屋顶应用经历整年四季的示范项目

Publication 文献发表

- LBNL, CU, and GPABR have published the first comprehensive study of cool roof policies and benefits in China:

  LBNL、重大、广东省建研院联名在国际期刊〈能源政策〉上发表了首篇关于中国冷屋顶政策及效果的论文：

  Gao Y, Xu J, Yang S, Tang X, Zhou Q, Ge J, Xu T, Levinson R. 2014. Cool roofs in China: Policy review, building simulations, and proof-of-concept experiments. *Energy Policy*, doi:10.1016/j.enpol.2014.05.036, 25pp.

Progress toward key Year 4 milestones (cool roof infrastructure) 冷屋顶基础设施项目第4年进展情况

Milestones (highlighting 4 of 18) 进度（列选出18项中的4项）	CY14 Q1 1季度	CY14 Q2 2季度	CY14 Q3 3季度	CY14 Q4 4季度
Simulate urban and global cooling in Guangzhou 对广州城区及整体降温进行模拟				
Start four-season black/white/garden roof demonstration in Chongqing 开始黑色屋面/白色屋面/种植屋面的实验示范				
Launch natural exposure testing program for roofing products in China 展开中国屋面材料自然老化的测试项目				
Draft model language for cool surface credits/ requirements in Guangdong 起草有关鼓励/要求建筑冷表面的建筑标准文字模块（广东为例）				

■ Scheduled completion完成时间 ◆ Actual completion实际完成

Unspent fraction of (carryover + Y4 DOE funds) as of 2014-08: 45%
到2014年8月为止，未使用第4年资金45%

Issues/Risks/Abatement: Unusually rainy weather this summer may require extension of Chongqing demonstration through summer 2015 存在问题及解决方案： 重庆今年的多雨反常天气将迫使示范项目延长到2015年夏季

Estimated CO_2 and energy savings

Target Market and Audience

- Widespread acceptance of cool roofs (and possibly cool walls) in both residential and commercial construction in China and the USA:
  - About 50% of the population in both countries live in hot-summer climates
  - Could upgrade 3B m^2 of roofs by 2025 at no cost (end-of-service-life replacement)

Impact of Project

- The wide scale adoption of this technology in China by 2025 will save 120 TBTU/y source energy and 10 Mt/y CO_2:
  - Near term: Demonstrated anti-soiling properties of Dow fabricated coatings
  - Intermediate term: Demonstrated reduced cooling costs for cool roof coated commercial and residential buildings
  - Long term: Global market size for roof coatings is estimated to be $800M/y with an annual growth rate of 3-5% (Dow estimate)

Appendix 1:
ANTI-SOILING COATINGS

Proposal for project continuation (anti-soiling coatings)

Proposal Concept

- Initial attempts to fabricate acrylic based anti-soiling coatings look promising but need to be studied further to both optimize the coating hydrophobicity (anti-soiling properties) and minimize water permeability which will limit the life of the coating
- Consequently we propose to continue to develop, optimize and test the acrylic anti-soiling coatings
  - Changes in silica surface functionalization to improve bonding and particle dispersion
  - Changes in particle size and distribution to minimize water permeability
  - Assess routes to moving the SHE extenders to the film surface
  - Assess routes to minimizing the resin coating of the HE extenders already at the film surface

Budget

- ORNL - $150K, LBNL - $100K, Total = $250K, Dow - in kind = $250K

Outcomes

- Acrylic based anti-soiling coatings with demonstrated performance advantages (increased soiling resistance over time) over existing cool roof coatings

Budget for project continuation (anti-soiling coatings)

Annual U.S. and China (estimated) project budget, spending, and cost-share by source (past, current, planned)

Project Budget: $350K (ORNL, CY13-CY14) + $150K (LBNL, CY13-CY14) - US only

Spending to Date: CY13 and CY14 cost to date = $240K (ORNL) + $70K (LBNL)

Additional Funding: Dow anti-soiling coating development work self funded

Budget History					
CY2013 (past)		CY2014 (current)		CY2015 (planned)	
DOE	Dow cost-share	DOE	Dow cost-share	DOE	Cost-share
$225K (ORNL) $25K (LBNL)	$250K	$125K (ORNL) $125K (LBNL)	$250K	$150K (ORNL) $100K (LBNL)	$250K

Schedule for project continuation (anti-soiling coatings)

Tasks	CY14 Q4	CY15 Q1	CY15 Q2	CY15 Q3	CY15 Q4
Q1: Complete first evaluation and optimization of acrylic based formulations					
Q2: Provide Dow with silica particles with improved surface functionalities and size distribution characteristics					
Q3: Complete pigmented formulation development and evaluation with optimized silica particles					
Q4: Complete accelerated microbial growth, soiling and environmental coating studies					

Appendix 2:
COOL ROOF INFRASTRUCTURE

Proposal for project continuation (cool roof infrastructure)

Concept

Continue to develop Chinese cool roof infrastructure by

- Completing four-season black/white/garden roof experiment(s) that demonstrate cool roof benefits
- Extending urban and global cooling modeling to other hot regions in China
- Initiating Chinese cool roof rating system based on natural exposure testing program
- Developing and promulgate cool roof credits for all hot-summer Chinese climates
- Designing large-scale cool surface experiment

Budget

- LBNL - $200K

Outcome

- Science-based cool roof credits and rating system accelerate deployment of cool roofs in China—saving energy, cooling cities, and creating Chinese market for U.S. cool roof manufacturers

Budget for project continuation (cool roof infrastructure)

LBNL budget:

$595K (CY11-14) + $200K (CY15)

LBNL spending to date:

$360K (CY11-14) + $130K (CY14 to date) = $490K

China funding:

Unknown—but 13 Chinese partners are investing substantial effort in demonstration, modeling, rating, and code development for cool roofs

Schedule for project continuation (cool roof infrastructure)

Tasks	CY15 Q1	CY15 Q2	CY15 Q3	CY15 Q4	CY16+
Complete, analyze, and publish four-season black/white/garden roof experiment					
Model urban and global cooling in hot-summer Chinese climates other than Guangzhou					
Develop Chinese cool roof rating system					
Develop Chinese cool roof credits					
Design large-scale cool surface experiment in China					

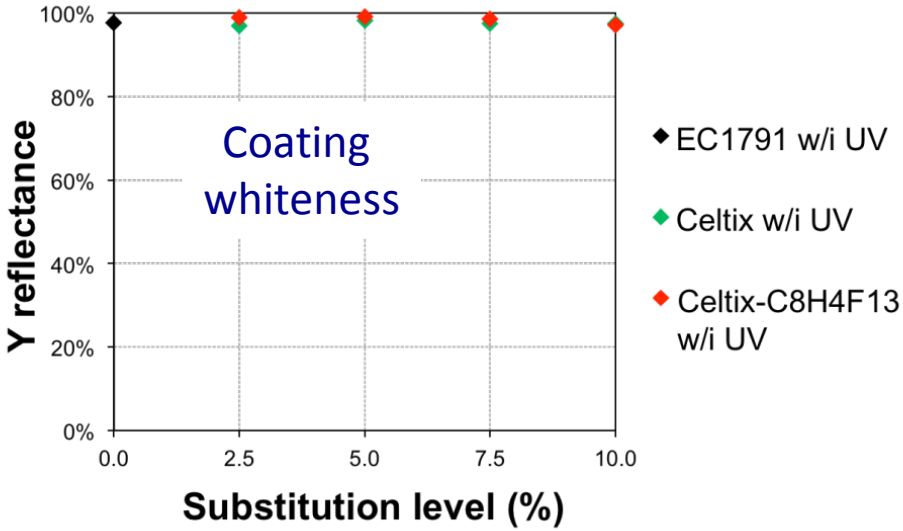
ADDITIONAL TECHNICAL SLIDES

Dispersability of SH Powders in a Latex Formulation

Replacement of $CaCO_3$	% SHE on Dry Film	Celtix No Silane	Celtix-$C_8H_4F_{13}$ Silane	Celtix-$C_{18}H_{37}$ Silane	Diafil 525 No Silane	Diafil $C_{18}H_{37}$ Silane	Diafil $C_8H_4F_{13}$ Silane
2.5%	0.87%	Y	Y	N			
5.0%	1.74%	Y	Y	N	Y	Y	Y
7.5%	2.61%	Y	Y	N			
10%	3.47%	Y	Y	N			
25%					Y		Y
33%					N		

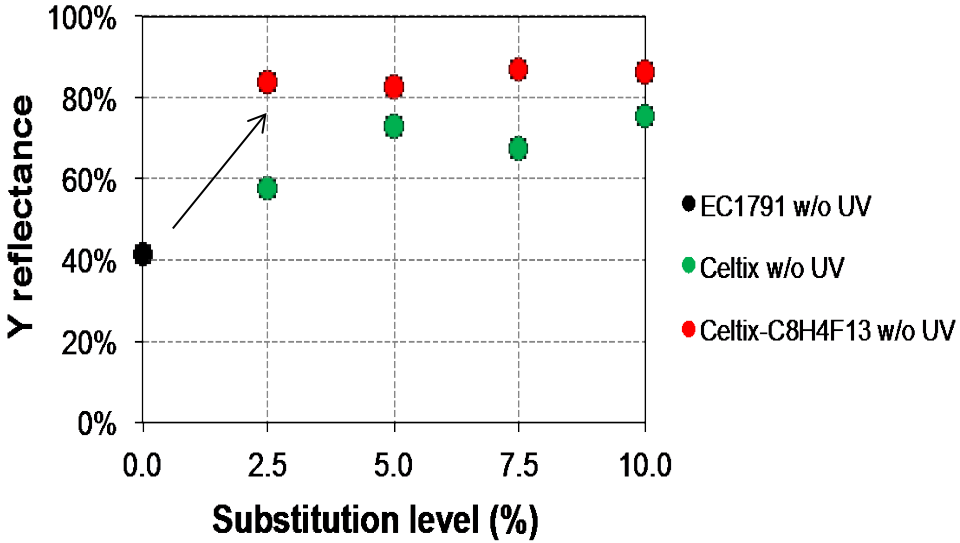
- Celtix-$C_8H_4F_{13}$ fluorinated silane DE was successfully dispersed at low levels into water based roof coating <u>using Tamol dispersant and high shear dispersator</u>
- Celtix-$C_{18}H_{37}$ alkyl silane DE was <u>not easily dispersible.</u> Grit and phase separation was observed possibly due to the large, long chain hydrophobic groups on the DE surface.
- Diafil fillers, both modified and unmodified, could be incorporated into the roof coating formulation at levels up to 5% volume substitution. The unmodified and fluoro-silane modified variants could be incorporated at levels up to 25% volume substitution.

Superhydrophobic Powder/Acrylic Coating Studies



Dirt Pick-up Resistance (DPUR) **with** UV Exposure

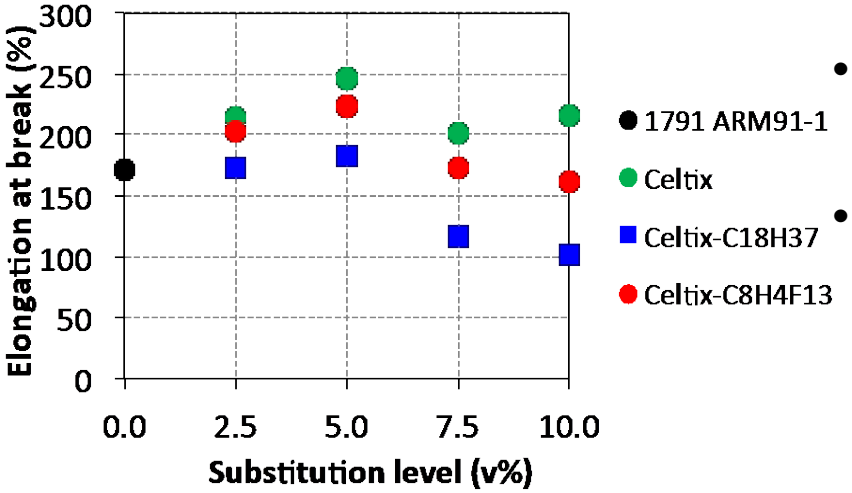
- Dirt resistance of EC1791 reference acrylic coating is unaffected by the presence of the SH particles



Dirt Pick-up Resistance (DPUR) **without** UV Exposure to deactivate DPUR chemistry

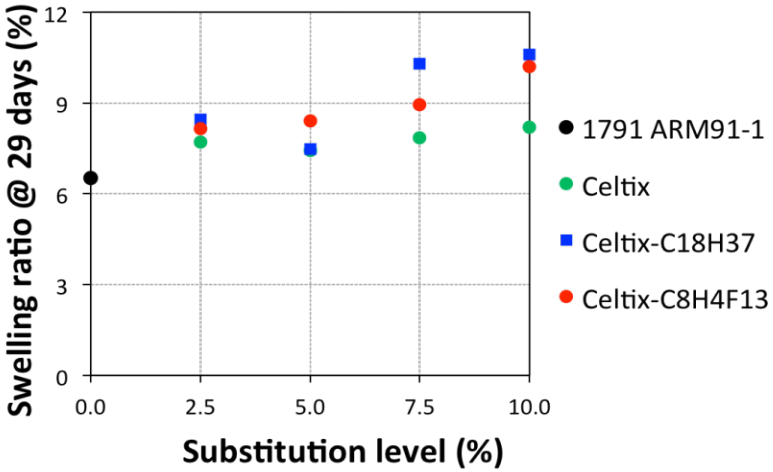
- The Y-reflectance, or whiteness of films with *any* Celtix modification was substantially higher than EC1791 in this test
- Y-Reflectance is highest with the fluorosilane modification which is effective at low use levels!

Superhydrophobic Powder/Acrylic Coating Studies



Film Elongation at Break Point

- Elongation at break values were dependant on extender: Celtix > Celtix-$C_8H_4F_{13}$ > Celtix-$C_{18}H_{37}$
- All samples showed elongation at break values of >100% and thus passed ASTM D6083 standard



Water Induced Swelling: Percent Water Pickup @ 29 Days

- All films that contained unmodified Celtix or SH powders showed higher water pickup @ 29 days than 1791/ARM91-1
- The swelling ratios @ 29 days of three Celtix appeared to increase as the substitution level increased

Film Properties with 5% Diafil and Celtix

Inorganic extenders	$CaCO_3$	Diafil	Celtix	Diafil-$C_{18}H_{37}$	Celtix-$C_{18}H_{37}$	Diafil-$C_8H_4F_{13}$	Celtix-$C_8H_4F_{13}$
Maximum stress (psi)	210 ± 1	239 ± 2	262 ± 2	273 ± 2	249 ± 2	236 ± 1	236 ± 1
Elongation at break (%)	250 C 4	226 ± 3	250 ± 20	210 ± 40	180 ± 30	230 ± 10	220 ± 20
Water permeance (US Perms)	23.6	23.1	17.8	16.0	14.2	15.1	12.9
Maximum swelling ratio (%)	16.3	14.4	14.5	14.2	13.8	14.3	14.6
Swelling ratio @ 1 month (%)	6.5	7.4	7.4	7.4	7.5	7.6	8.0
Contact Angle (degrees)	102.6±2.1		106.9±2.3		104.9±1.6		105.2±1.5

- Unmodified Diafil, Diafil-$C_{18}H_{37}$, and Diafil-$C_8H_4F_{13}$ were included in the 1791 ARM91-1 formulation at 5.0 v % substitution of $CaCO_3$.
- The tensile and elongation properties of films with Diafil fell between 1791 and those with Celtix, in line with the oil absorption trend.
- Water uptake was independent of the DE grades
- Films that contain Celtix or Diafil with the same surface functionality show very similar maximum water swelling ratios and swelling ratios at 1 month.

Film Properties with 25% Diafil or Celtix

Inorganic extenders	$CaCO_3$	Unmodified Celtix	Unmodified Diafil	Diafil $C_8H_4F_{13}$
Maximum stress (psi)	184 ± 1	301 ± 6	268 ± 4	177 ± 2
Elongation at break (%)	249 ± 1	120 ± 8	137 ± 6	166 ± 9
Water permeance (US Perms)	23.6	78.6	52.5	10.4
Maximum swelling ratio (%)	18.0	13.9	11.9	17.9
Swelling ratio @ 1 month (%)	6.7	8.9	8.4	12.9
Contact Angle (degrees)	102.6±2.1	126.8±1.2	110.0±2.3	

- A trial of 33 v % substitution by Diafil-$C_8H_4F_{13}$ was first carried out but was not successful even when the PVC was lowered to 33% (VS was kept the same) as extensive grits were observed.

- However, Diafil-$C_8H_4F_{13}$ was successfully included at 25 v % while the PVC and VS were kept the same. The wet coatings were homogeneous and the surface of dried films looked smooth.

- Similar to previous results with Celtix-containing films, the elongation at break value was lower than those of the films with 5% substitution, but still met the ASTM D-6083 standard. Although the permeance of the film containing 25 v% of the Diafil-$C_8H_4F_{13}$ is reduced relative to the control, the water swelling ratios are either the same or higher.

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