From Local Cooling to Global Cooling: Cool Roofs and Cool Pavements
从地方冷却到全球冷却：冷屋顶和冷铺路面

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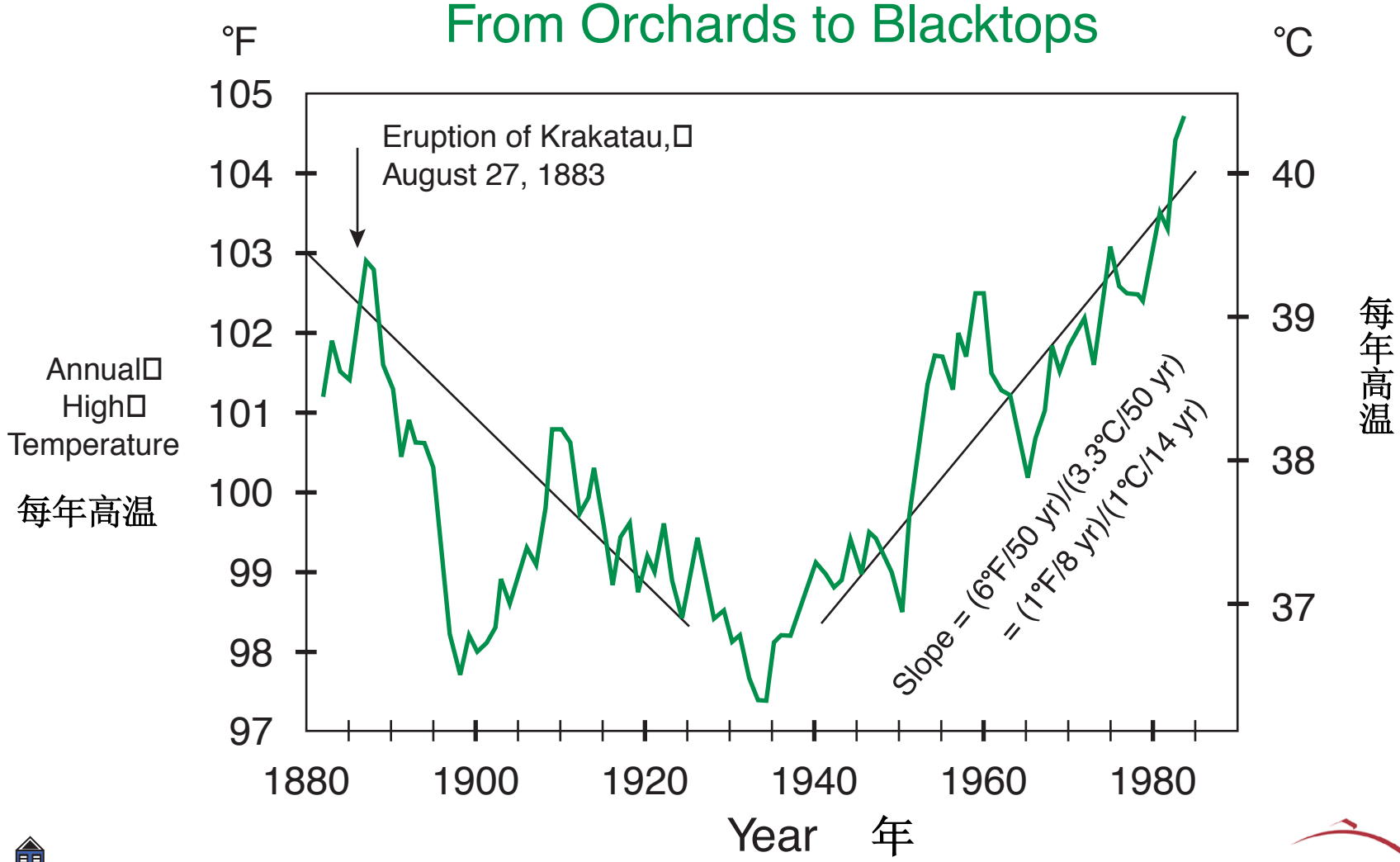
Temperature Trends in Downtown Los Angeles
洛杉矶市中心的气候变化曲线

From Orchards to Blacktops



White is ‘cool’ in Bermuda
在百慕大：白色是很“酷”的

and in Santorini, Greece
在希腊的圣托里尼岛也是这样

Cool Roof Technologies
冷屋顶技术

Old 老一代技术

flat, white
平顶，白色

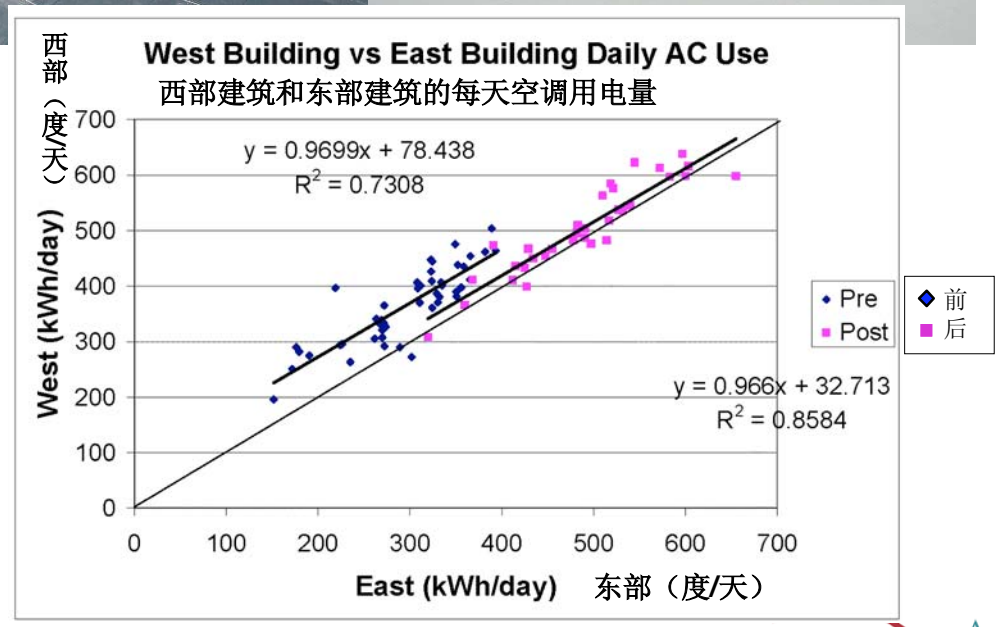
pitched, white
低坡屋顶，白色

New 新一代技术

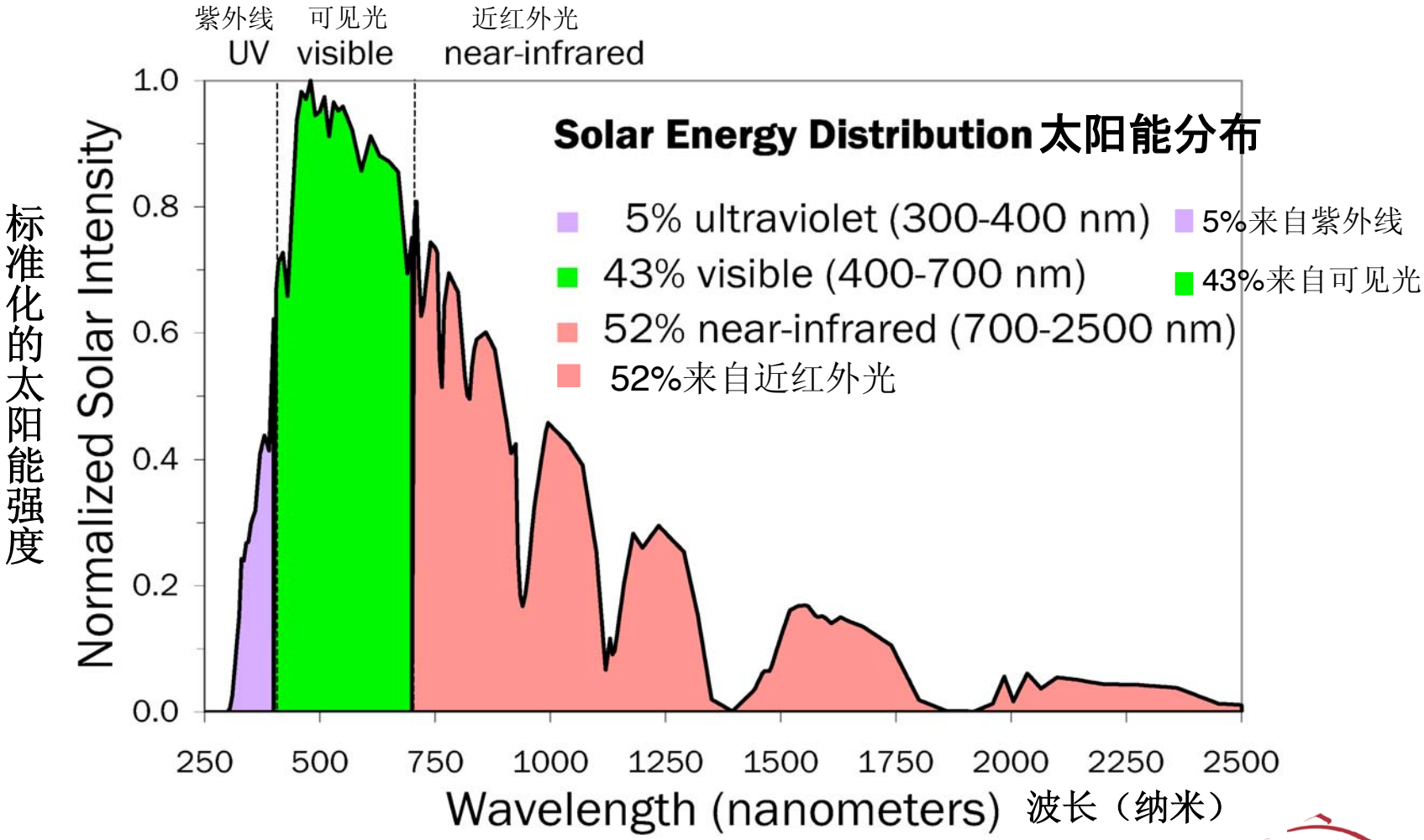
pitched, cool & colored
低坡屋顶，降温 & 多彩

Cool Roof Programs around the World
世界范围内的冷屋顶项目

- U.S. 美国
- Europe 欧洲
- Asia 亚洲
- Middle East 中东
- China 中国
- India (Hyderabad demos; see graph at right)
  印度 （在海德拉巴市示范，见右图）



Cool Colors Reflect Invisible Near-Infrared Sunlight
冷色可以反射看不见的近红外日光

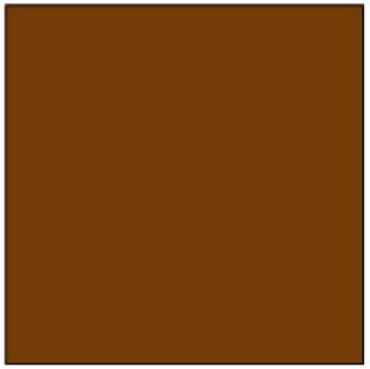


Cool and Standard Brown Metal Roofing Panels
对比：两块金属屋顶面板
冷色的棕色和标准的棕色

- Solar reflectance ~ 0.2 higher
- 太阳辐射反射率 ～0.2 以上
- Afternoon surface temperature ~ 10ºC lower
- 午后表面温度 ～低于10ºC

Courtesy BASF Coatings
感谢BASF公司

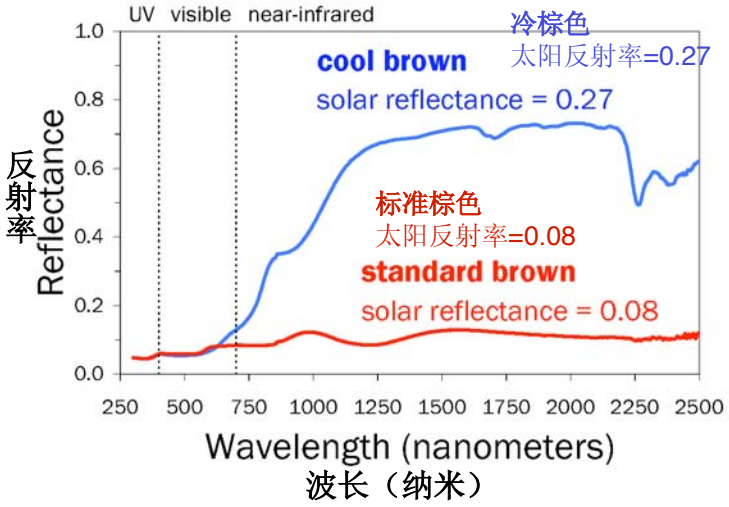
冷色
cool



solar reflectance = 0.27
thermal emittance = 0.85
roof temp – air temp = 36ºC (65ºF)
太阳反射率=0.27
热辐射率=0.85
屋顶温度与空气温度之差为：36 ºC

标准色
standard

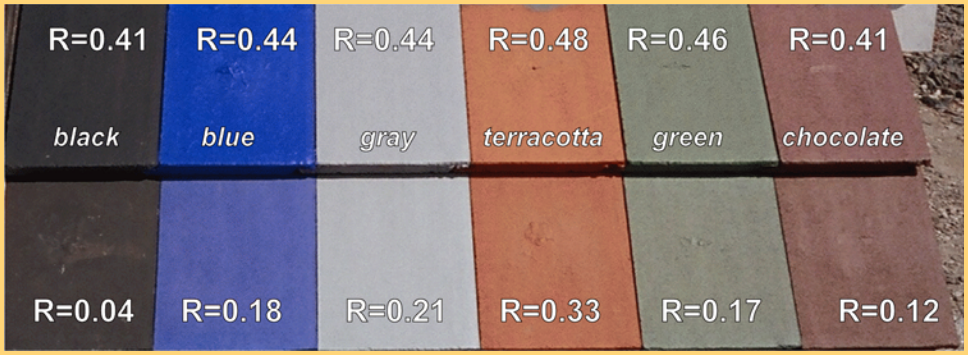
solar reflectance = 0.08
thermal emittance = 0.85
roof temp – air temp = 45ºC (81ºF)
太阳反射率=0.08
热辐射率=0.85
屋顶温度与空气温度之差为：45 ºC



Designing Cool Colored Roofing
设计彩色的冷屋顶

冷色混凝土瓦
cool concrete tile
R ≥0.40

标准色混凝土瓦
standard concrete tile
(同种颜色 same color)



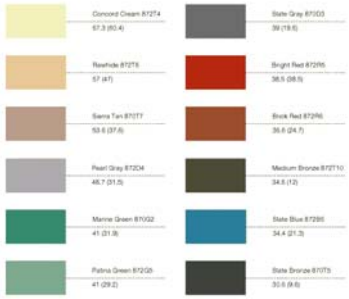
Courtesy American Rooftile Coatings
感谢美国 Rooftile Coatings 公司提供

solar reflectance gain =
太阳能反射增益

+0.37	+0.26	+0.23	+0.15	+0.29	+0.29

冷色粘土瓦
cool clay tile
R ≥0.40

Courtesy
MCA Clay Tile
感谢MCA Clay Tile
公司提供



冷色金属
cool metal
R ≥0.30

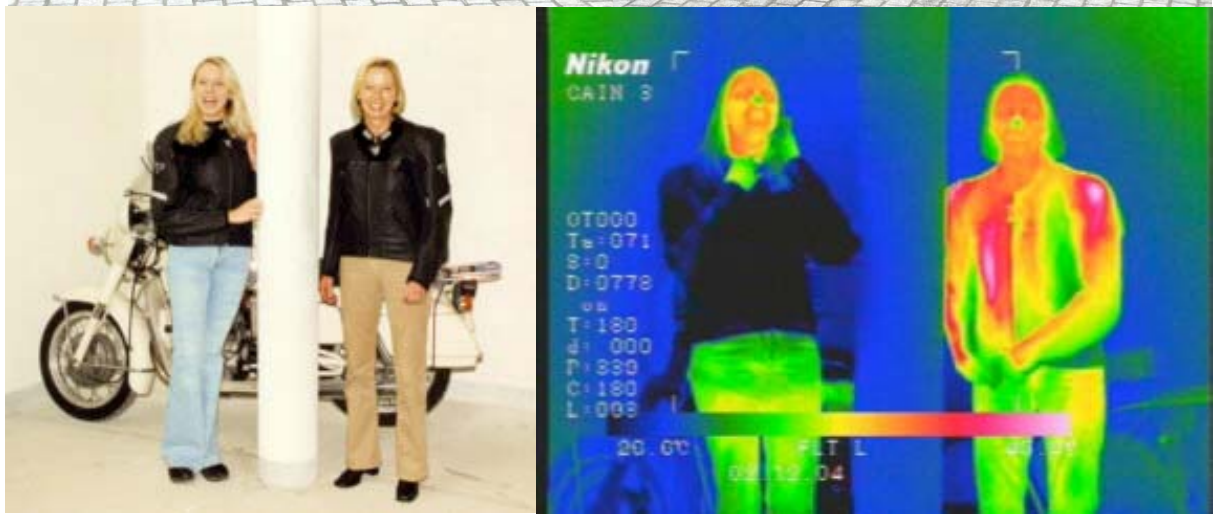
Courtesy
BASF Industrial Coatings
感谢BASF公司提供

冷色玻璃纤维沥青屋顶板（shingle）
cool fiberglass asphalt shingle
R ≥0.25
Courtesy Elk Corporation
感谢 Elk公司

Cool is Cool:
From Cool Color Roofs to Cool Color Cars and Cool Color Jackets
冷色就是“酷”：从彩色的冷屋顶、冷轿车，再到冷外套

Toyota experiment (surface temperature 10ºC cooler)

丰田公司的实验表明：冷色轿车的表面温度要比标准色轿车低**10**ºC



Ford is also working on the technology

福特公司也正在研究这项技术

Courtesy: BMW (http://www.ips-innovations.com/solar_reflective_clothing.htm)

来源于： **BMW** 宝马汽车公司

Cool Paving Materials:
冷铺路面材料

Concrete	**(a)** Unexposed	**(b)** Weathered	**(c)** Weathered, wetted	**(d)** Soiled	**(e)** Abraded	**(f)** Formed
C1:S1:R2 gray cement/ riverbed sand/ granite rock	ρ=0.44	ρ=0.34	ρ=0.14	ρ=0.43	ρ=0.24	ρ=0.25

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Reflective Pavements are Cooler
反射路面温度更低，更“酷”

- **Fresh asphalt**
  新铺的沥青路面

Albedo反照率: 0.05
Temperature: 123°F
温度：**52.8°C**

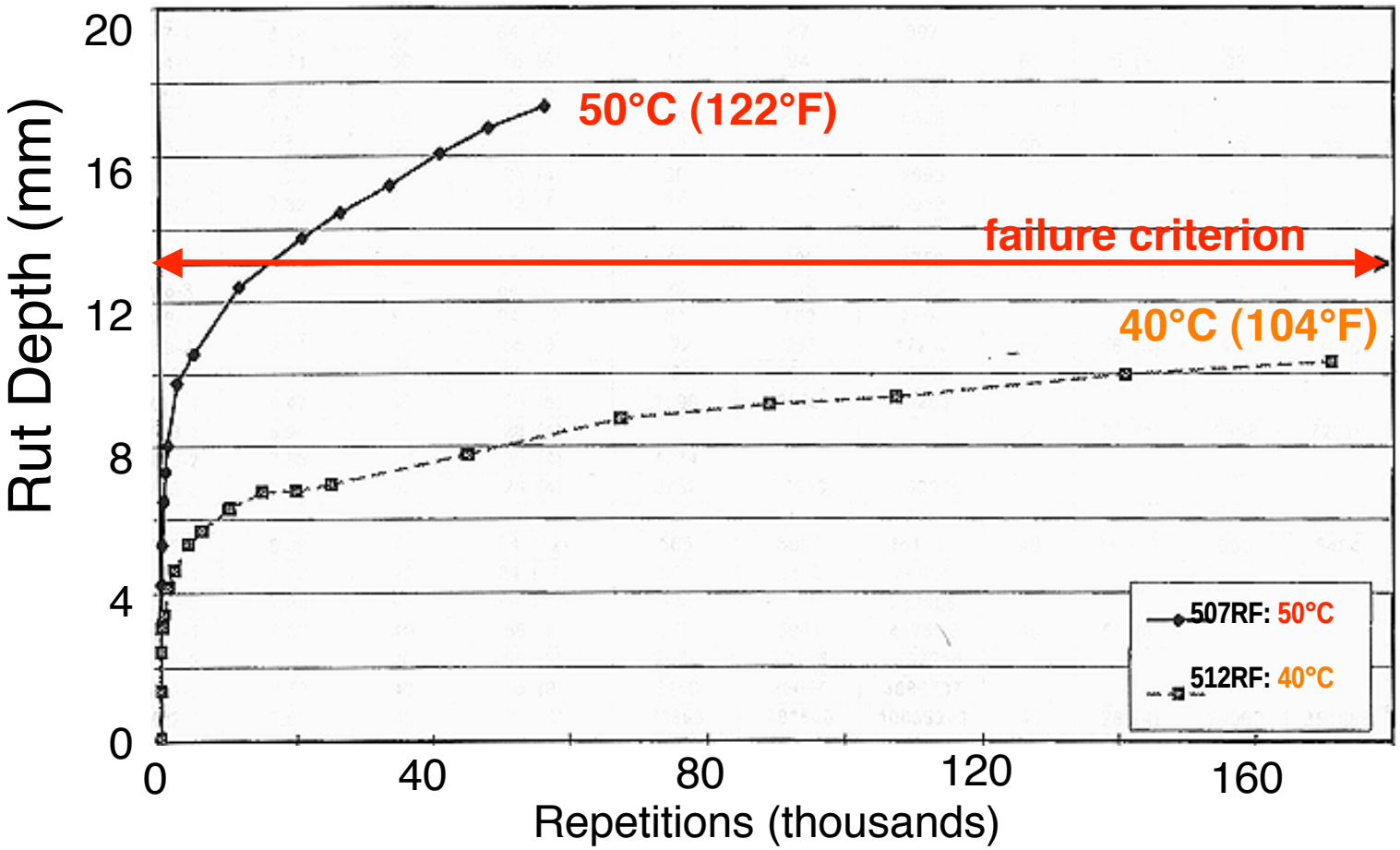
- **Aged asphalt**
  老旧的沥青路面

Albedo反照率: 0.15
Temperature: 115°F
温度：**46°C**

- **Prototype asphalt coating**
  沥青涂层样品

Albedo 反照率: 0.51
Temperature: 88°F
温度：**31°C**

Temperature Effect on Rutting

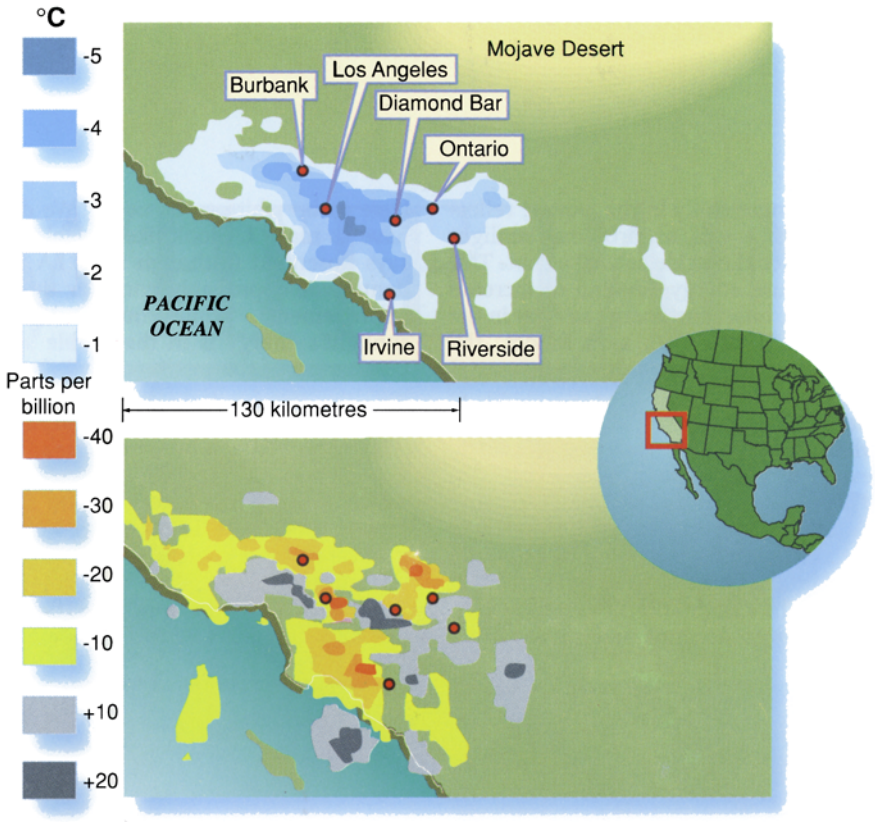


Source: Dr. John Harvey, UC B Civil Engineering, Inst. Transpo. Studies

Simulated Meteorology and Air-quality Impacts in LA
洛杉矶的模拟气象和空气质量影响

气温变化 Temperature Change

臭氧浓度变化 Ozone Concentration Change



Potential Savings in LA (1998)

Current costs have more than doubled*

*Source: Rosenfeld et al. *Energy and Buildings* (28), p51-62, 1998

洛杉矶的潜在节余能力 (1998年)

目前的成本是1998年的2倍*

*来源： Rosenfeld et al. *Energy and Buildings* (28), p51-62, 1998

- **Savings for Los Angeles (1998)**

  洛杉矶的节余金额：

  - Direct, $100M/year 直接节省：1亿美元/年
  - Indirect, $70M/year 间接节省：7千万美元/年
  - Smog, $360M/year

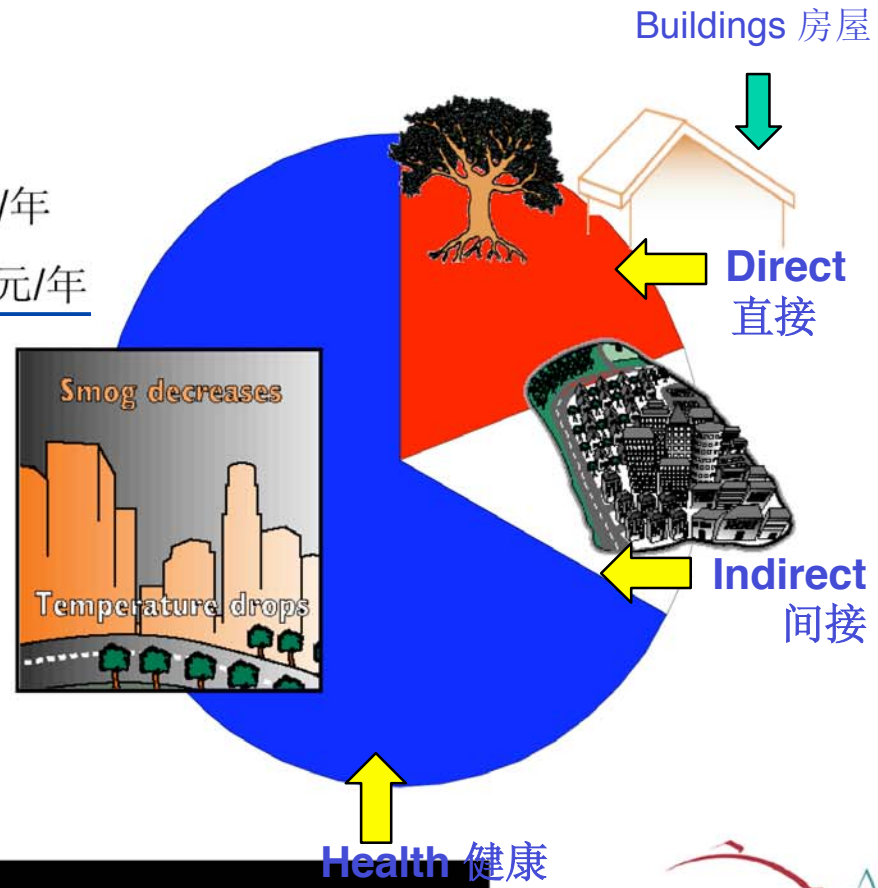
    烟雾节省：3亿6千万美元/年

- **Estimate of national savings:**

  $5B/year

  据估计，全美国的节余金额为：

  50亿美元/年



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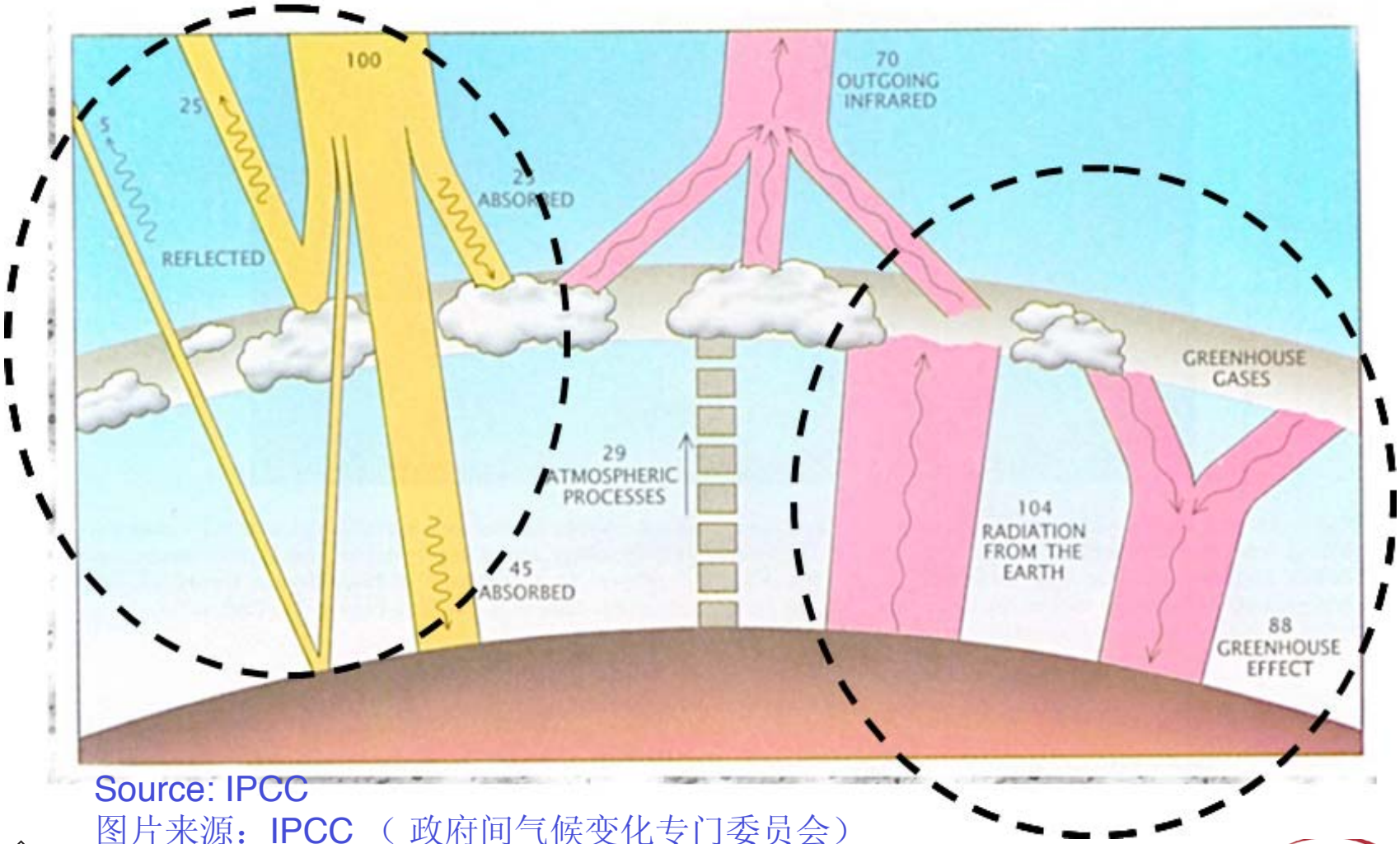
Cool Surfaces also Cool the Globe
冷色表面也能让全球降温

- Cool roof standards are designed to reduce a/c demand, save money, and save emissions. In Los Angeles they will eventually save ~$100,000 per ***hour***
- 根据设计标准，冷屋顶可降低住户对空调的需求，既省钱又减排。在洛杉矶，冷屋顶最终可以实现***每小时***节约10万美元
- Annual savings in the U.S. = $1-2B; ~ 7 M tons CO_2
- 冷屋顶在全美国的年度节余金额为：10-20亿美元；约700万吨CO_2
- Annual savings in the world = $10-15B; ~ 100 M tons CO_2
- 冷屋顶在全世界的年度节余金额为：100-150亿美元；约1亿吨CO_2
- BUT higher albedo surfaces (roofs and pavements) directly cool the world quite independent of avoided CO_2.
- **但是! 高反照率的表面（如冷屋顶和冷铺路面）虽然可以直接降低温度，但却与减少CO_2排放量没有直接联系**

Solar Reflective Surfaces Also Cool the Globe
太阳能反射表面——也能让全球变得更凉爽



Source: IPCC
图片来源：IPCC （政府间气候变化专门委员会）

Effect of Solar Reflective Roofs and Pavements in Cooling the Globe
太阳能反射屋顶和路面对全球降温的作用

(Source: Akbari, Menon, Rosenfeld. *Climatic Change*, 2008)

（来源： Akbari, Menon, Rosenfeld. *Climatic Change*, 2008）

	Δ Solar Reflectivity Δ太阳能反射率	CO_2 Offset by 100 m^2 每100m^2 抵消的CO_2	CO_2 Offset Globally 全球范围内抵消的CO_2
White Roof 白色屋顶	0.40	10 tons **	
Average Roof * 屋顶平均*	0.25	6.3 tons	24 Gt
Cool Pavement 冷铺路面	0.15	4 tons	20 Gt
Total Potential 总体潜能			44 Gt
Value of 44 Gt CO_2 at \$25/t ~ \$1 Trillion 若按每吨25美元的CO_2计算，44Gt的CO_2，共可节省约1万亿美元			

* White Roof will be "diluted" by cool colored roofs of lower reflectivity, and roofs that can not be changed, because they are long-lived tile, or perhaps they are already white.
白色屋顶被有更低反射率的冷彩色屋顶"冲淡"了，而且房顶一般不会改变，因为他们是长寿命的瓦片，或者他们已经是白色的了。

** Compare 10 tons with a family car, which emits ~4 tons/year.
可以把这10吨抵消的CO_2，与一辆家庭用车比较。一辆家庭用车每年排放4吨CO_2。

A Global Action Plan: The Big Picture
从全局来看：全球行动计划

- Develop an international to install cool roof/pavement in world's100 largest cities
- 建立一个国际项目，在世界最大的100个城市中安装冷屋顶或冷铺路面
- This is a simple measure that we hope to organize the world to implement **AND**
- 这是一项比较简单的措施，因此我们希望能够联合世界各国来实践它，而且
- **WE'D BETTER BE SUCCESSFUL!**
- 我们应该更好地让这个计划成功！
- We can gain practical experience in design of global measures to combat climate change
- 我们可以在设计全球规模的措施中，获得实践中的经验教训，从而对抗气候变化

Now remember this 请记得

100 m^2 of a white roof, replacing a dark roof, offset the emission of 10 tons of CO_2

每用**100**平方米的白色屋顶替代黑色屋顶，就可以抵消**10**吨的**CO_2**