

Essentials of Laboratory Weathering 实验室老化机理

Sunny Sun | 孙杏蕾

Q-Lab

[点击查看课程资料 and 视频回放](#)

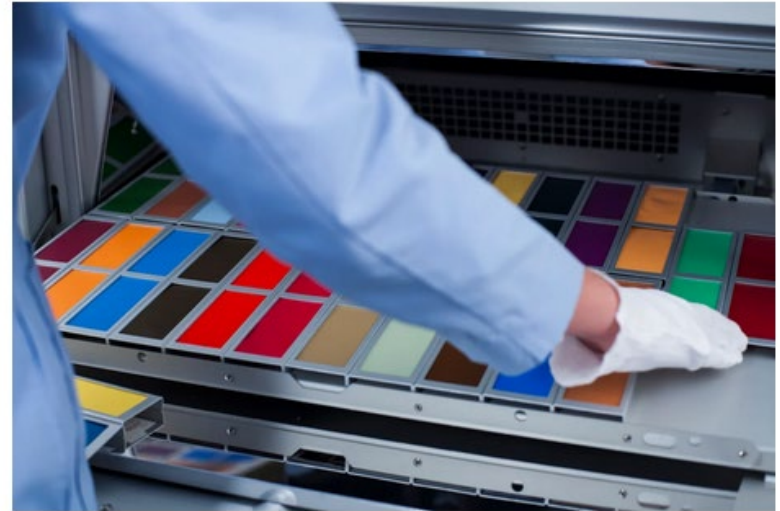
Administrative Notes

You'll receive a follow-up email from info@email.q-lab.com with links to a survey, registration for future webinars, and to download the slides

Use the **Q&A feature in Zoom** to ask us questions today!



We make testing simple.



Thank you for attending our webinar!

We hope you found our *Essentials of Laboratory Weathering* webinar to be helpful and insightful. The link below will give you access to the slides and recorded webinar.

What We Will Talk About 内容

- Basics of Weathering 老化机理
- Why Perform Laboratory Weathering? 为什么进行实验室加速老化？
- Laboratory Weathering Testing 实验室老化测试
 - Xenon 氙灯
 - Fluorescent UV 荧光紫外灯
- Elements of an Effective Testing Program 有效测试方案的要素

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Weathering: 老化

Changes in material properties resulting from exposure to the radiant energy present in **sunlight** in combination with **heat** (including temperature cycling) and **water** in its various states, predominately as humidity, dew, and rain.

由于暴露于**阳光**中受到紫外辐射，以及**热**（包括温度循环）和**水**（主要是湿度、露水和雨水）而导致的材料性能的变化。



Sunlight



Heat



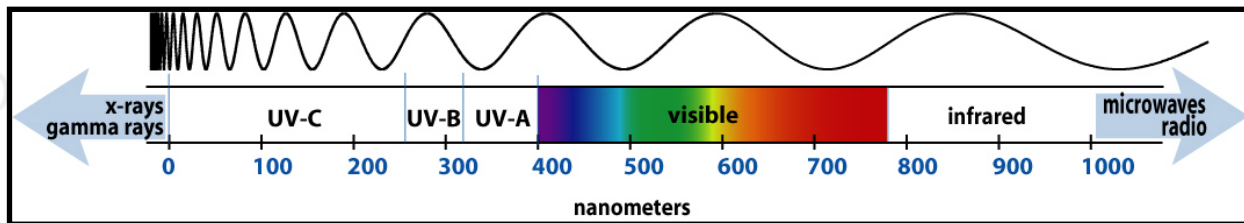
Water

Sunlight 光

- A form of energy
- 能量的形式
- Electromagnetic radiation
- 电磁辐射
- Usually described in terms of **irradiance** & **wavelength** (λ)
- 通常用**辐照度**和**波长**行描述



Electromagnetic Spectrum 电磁光谱

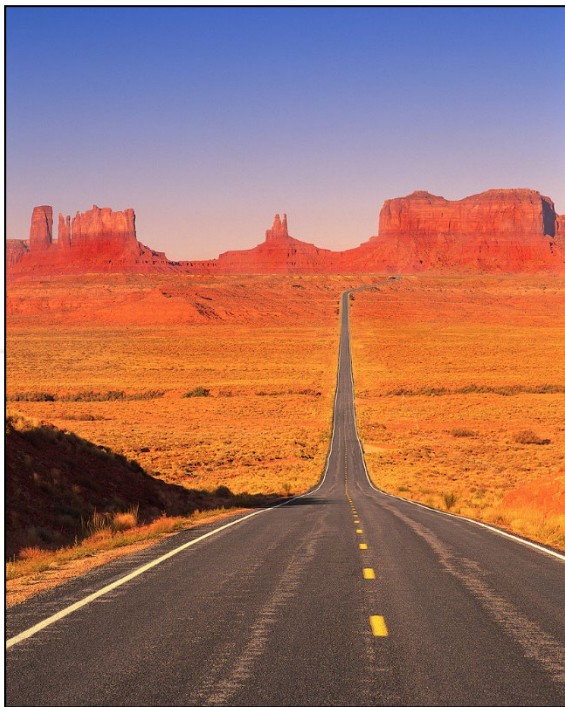


Sunlight

UV causes virtually all polymer degradation!
紫外线几乎导致所有聚合物降解

UV	295-400 nm	~7%
Visible	400-800 nm	~55%
IR	800-3000 nm	~38%

Irradiance 辐照度



Irradiance¹ is the rate at which light energy falls on a surface, per unit area

[W/m²] or [J/s·m²]

辐照度 – 单位面积上的功率

Spectral irradiance² is the irradiance of a surface per unit wavelength

[W/m²/nm]

光谱辐照度 – 某波长下的辐照度

Radiant exposure¹ (or radiant dosage) is irradiance over a period of time

[J/m²] or [W·s/m²]

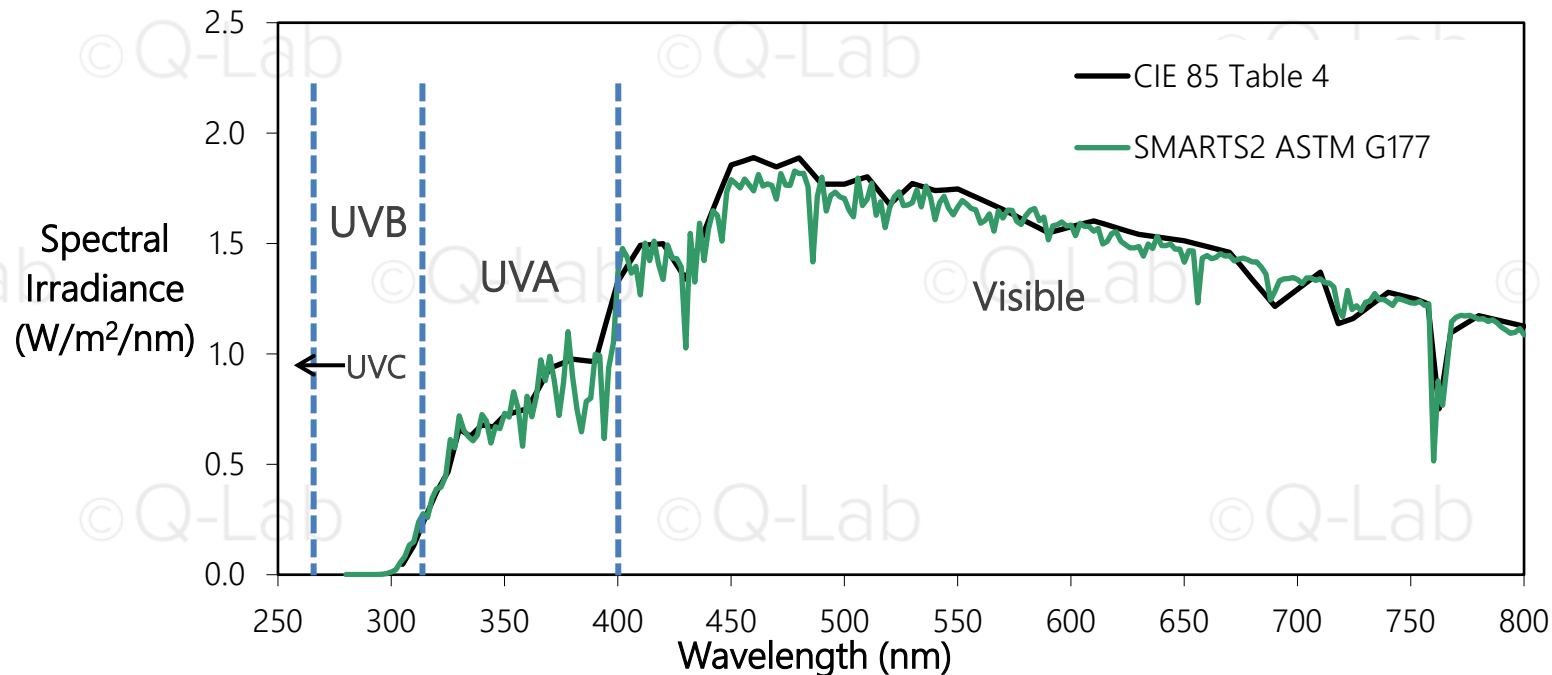
辐射曝晒总量 – 辐照度与时间的乘积

1 ASTM G113 – Terminology

2 ISO 9288 – Physical quantities and Definitions

Spectral Irradiance 光谱辐照度

Also called Spectral Power Distribution, or SPD 光谱能量分布



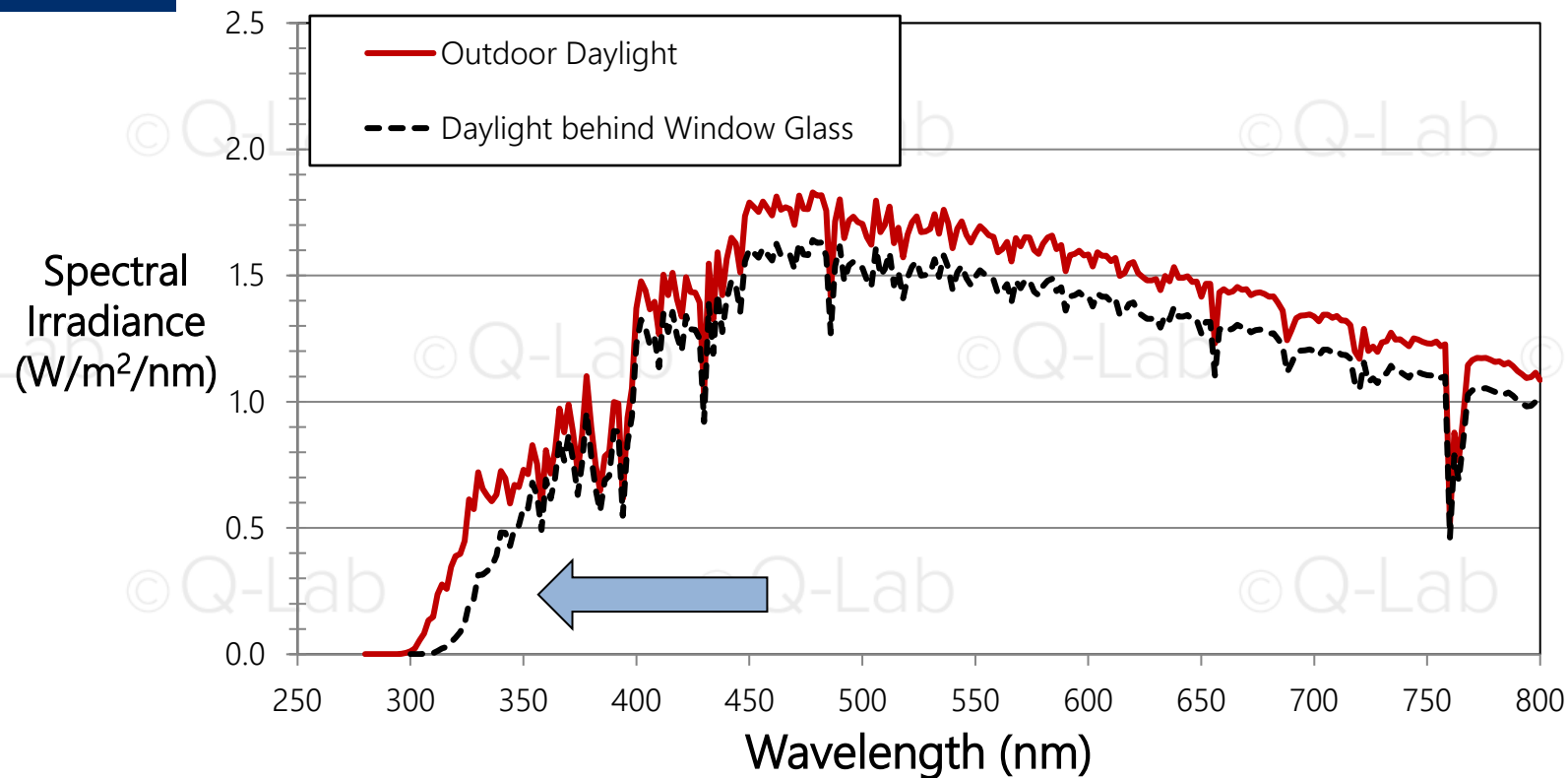
The absolute or relative radiant power emitted by a source, or incident upon a receiver as a function of wavelength. (ASTM G113)

Spectrum Modifiers 光谱变化

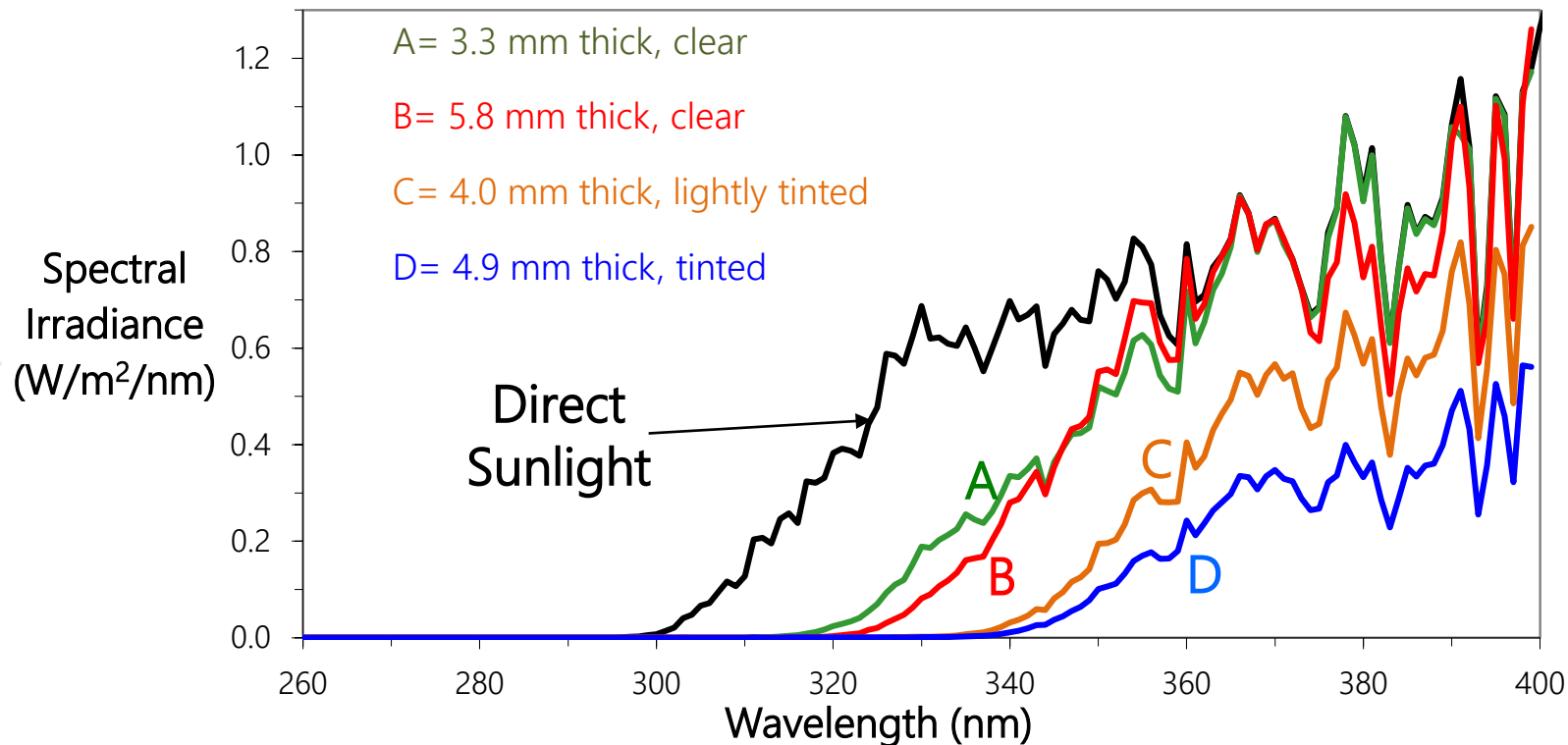


- Sun angle 太阳角度
 - Time of Year (e.g. summer)
 - Time of Day (e.g. noon)
 - Latitude
- Altitude 海拔

Sunlight Through Window Glass 太阳光透过窗玻璃

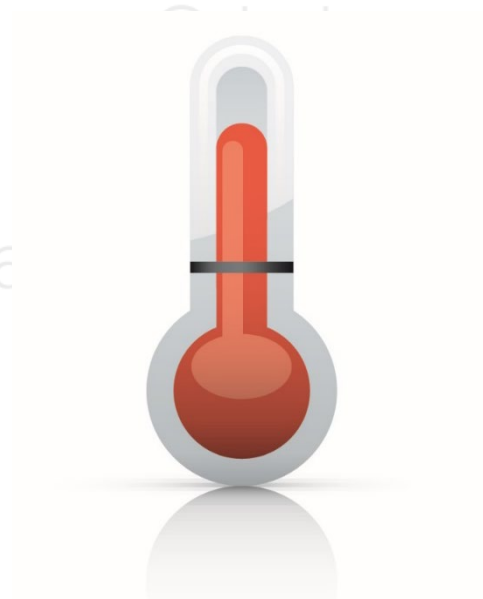


Sunlight Through Automobile Glass 太阳光透过汽车玻璃



Heat Effects 热效应

- Elevated specimen temperature 样品温度升高
- Dimensional change 形变
- Evaporation 蒸发
- Thermal aging 热老化
- Thermal cycling 热循环



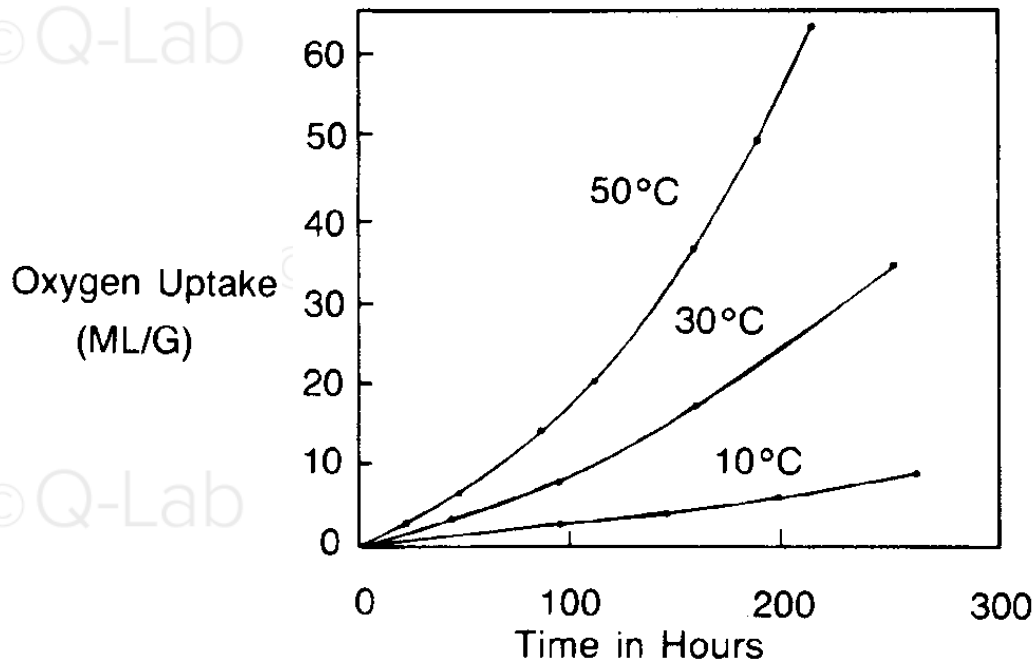
Photochemical Reactions and Heat 光化学反应与热



- Photochemical reactions are **not** usually simple one-step reactions
- 光化学反应通常**不是**简单的一步反应
- Primary photochemical reactions *are not* affected by heat
- 起初的光化学反应**不受**热影响
- Secondary photochemical reactions *are* affected by heat
- 随后的光化学反应**受**热影响

Effect of Temperature: 温度的影响

Oxidation Rate of Polyethylene 聚乙烯的氧化速率

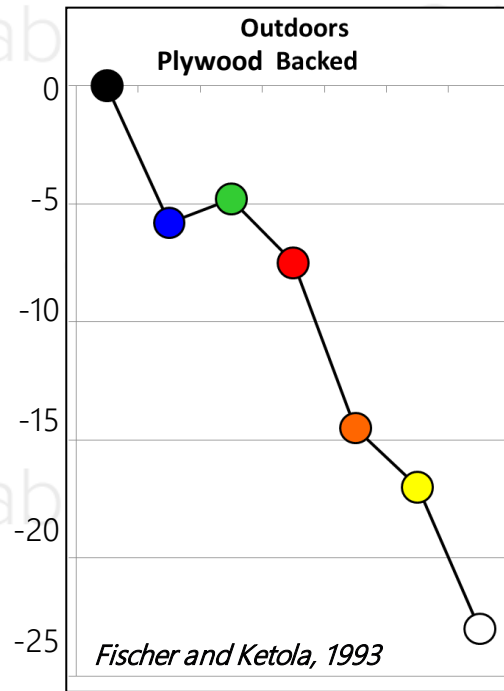
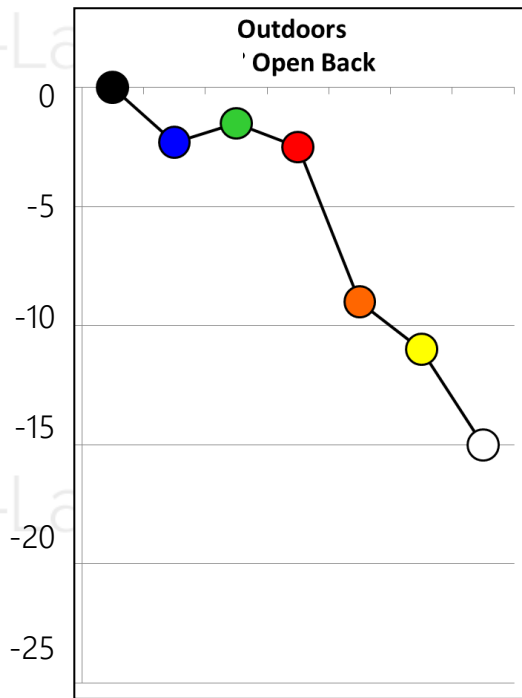


**Time In Hours Exposed to UV lamps*

Temperature and Color 温度和颜色

Darker Colors Have Higher Temperatures! 颜色越深，温度越高

Temperature Δ
(°C)



Heat behind Window Glass 车窗玻璃下的热



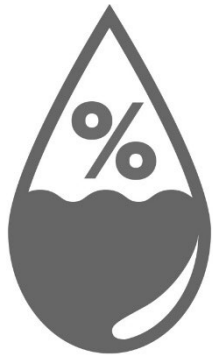
Temperature of automobile interior components behind window glass can exceed 100 °C

Water 水

- Chemical Reactions 化学反应
 - Reactions in solution 溶液中的反应
 - Facilitates reaction via increase in oxygen transport 通过增加氧气输送促进反应
- Physical Effects 物理效应
 - Erosion 侵蚀 (雨水冲刷)
 - Absorption/freeze-thaw 吸收/冻融
 - Thermal shock 热冲击
 - Impact (material loss) 冲击，剥离脱落



Forms of Water 水/潮湿的形式



Relative Humidity
相对湿度

Time of Wetness



Rain 雨水

Thermal Shock and Erosion



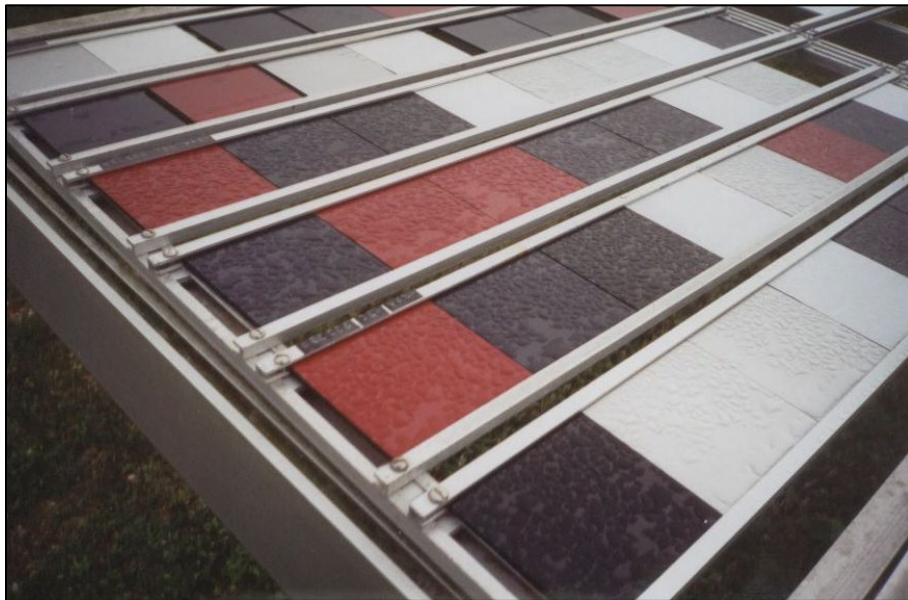
Dew 露水

Most Outdoor Wetness

Materials outdoors are wet longer than you think 12+ hours/day

Dew, not Rain, Is the Source of Most Outdoor Wetness!

露水，不是雨水，是戶外主要的潮濕因素！



Don't Underestimate the Effect of Moisture!

不要低估潮湿的影响

- Changes the **rate** of degradation 改变老化的**速率**
- Changes **mode** of degradation 改变老化的**模式**
- Difficult to accelerate 很难加速

Summary: Forces of Weathering 总结：老化因素

- Sunlight 光
 - UV is most damaging for most durable materials
 - Material-specific “Spectral Sensitivity” affects degradation
- Temperature 温度
 - Includes both heat and thermal cycling
 - Influences secondary reactions
- Water 水
 - Dew is responsible for most wetness
 - Rainfall and humidity also contribute to weathering

Weathering includes synergistic effects between these factors!

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Why Test? 为什么做测试?

- Meet specifications
- Avoid catastrophes
- Enhance your reputation
- Verify supplier claims
- Improve product durability
- Save on material costs
- Expand existing product lines
- Enter new markets
- Outrun the competition
- Stay ahead of regulations

Laboratory Testing is a Tool for Directional Decision-Making

实验室测试是定向决策的工具

Laboratory Accelerated tests can help you:

实验室加速测试可以帮你：

- Make decisions better and/or faster
- 做更好更快的决策
- Reduce risk of making bad decisions
- 降低做出错误决策的风险
- Reduce risk of making decisions too slowly
- 降低决策速度过慢的风险

What Kind of Test Should I Run?

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control	Pass / fail	• Defined • Short	Material specification

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Accelerated Test Type	Result	Test Time	Results compared to
Quality Control	Pass / fail	• Defined • Short	Material specification
Qualification / validation	Pass / fail	• Defined • Medium-long	Reference material or specification

What Kind of Test Should I Run?

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control	Pass / fail	• Defined • Short	Material specification
Qualification / validation	Pass / fail	• Defined • Medium-long	Reference material or specification
Correlative	Rank-ordered data	• Open-ended • Medium	Natural exposure (Benchmark site)

What Kind of Test Should I Run? 应该运行哪种测试?

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control	Pass / fail	• Defined • Short	Material specification
Qualification / validation	Pass / fail	• Defined • Medium-long	Reference material or specification
Correlative	Rank-ordered data	• Open-ended • Medium	Natural exposure (Benchmark site)
Predictive	Service life Acceleration factor	• Open-ended • Long	Natural exposure (Service environment)

Advantages of Accelerated Lab Testing 实验室加速测试的优势

- Fast 快速
- Repeatable 可重复
- In-house 室内
- Great for Quality Control, Qualification, and Research & Development
- 非常适合质量控制，认证和研发

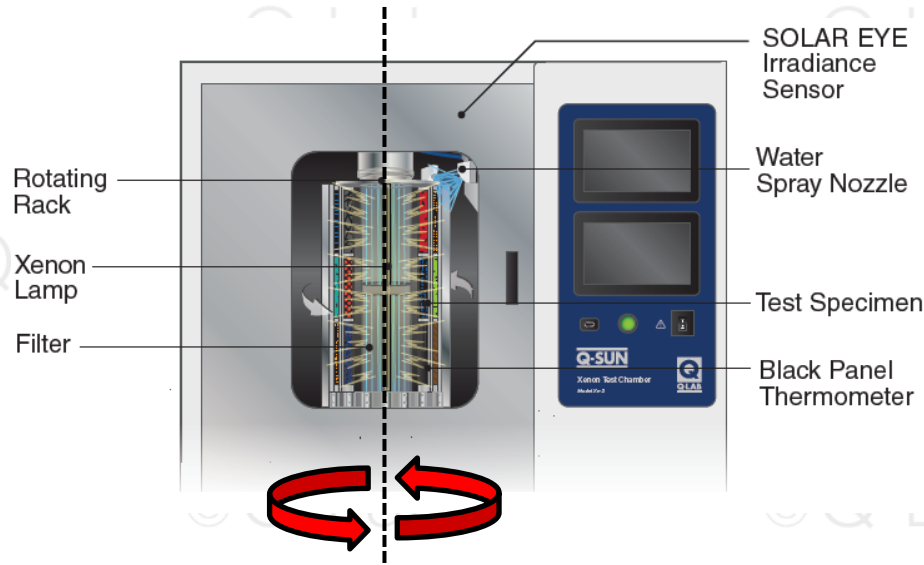
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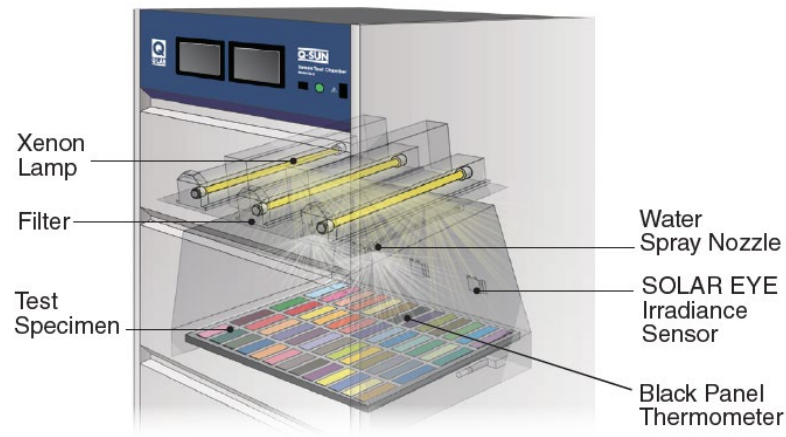
Xenon Arc 氙灯

Laboratory Weathering 实验室老化

Xenon Arc Test Chamber 氙灯老化试验箱



Rotating Rack 转鼓式



Flat Array 平板式

Xenon Arc Lamps 氙灯灯管

Air-cooled
风冷



Water-cooled
水冷



Water-cooled
Assembly
水冷组件



Xenon Arc Spectra 氙灯光谱

Major Influencing Factors 主要影响因素

- Optical filters 过滤片
- Irradiance level (intensity) 辐照度
- Wavelength at which irradiance is controlled ("control point") 控制点
- Lamp aging 灯管老化

Overview of Filters 过滤片

- Daylight 日光
- Window 窗玻璃
- Extended UV 紫外延展

Rotating drum "lantern"

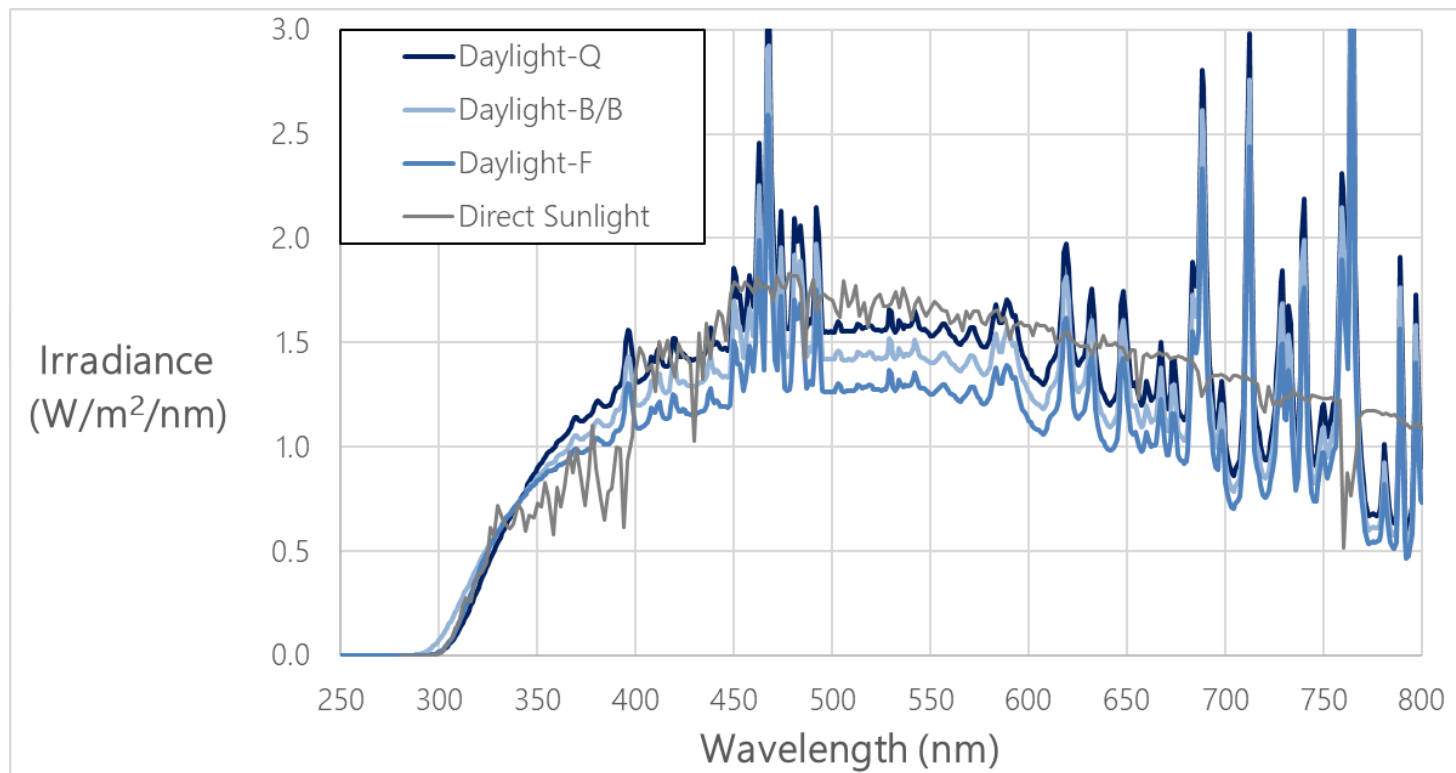


Flat array filter

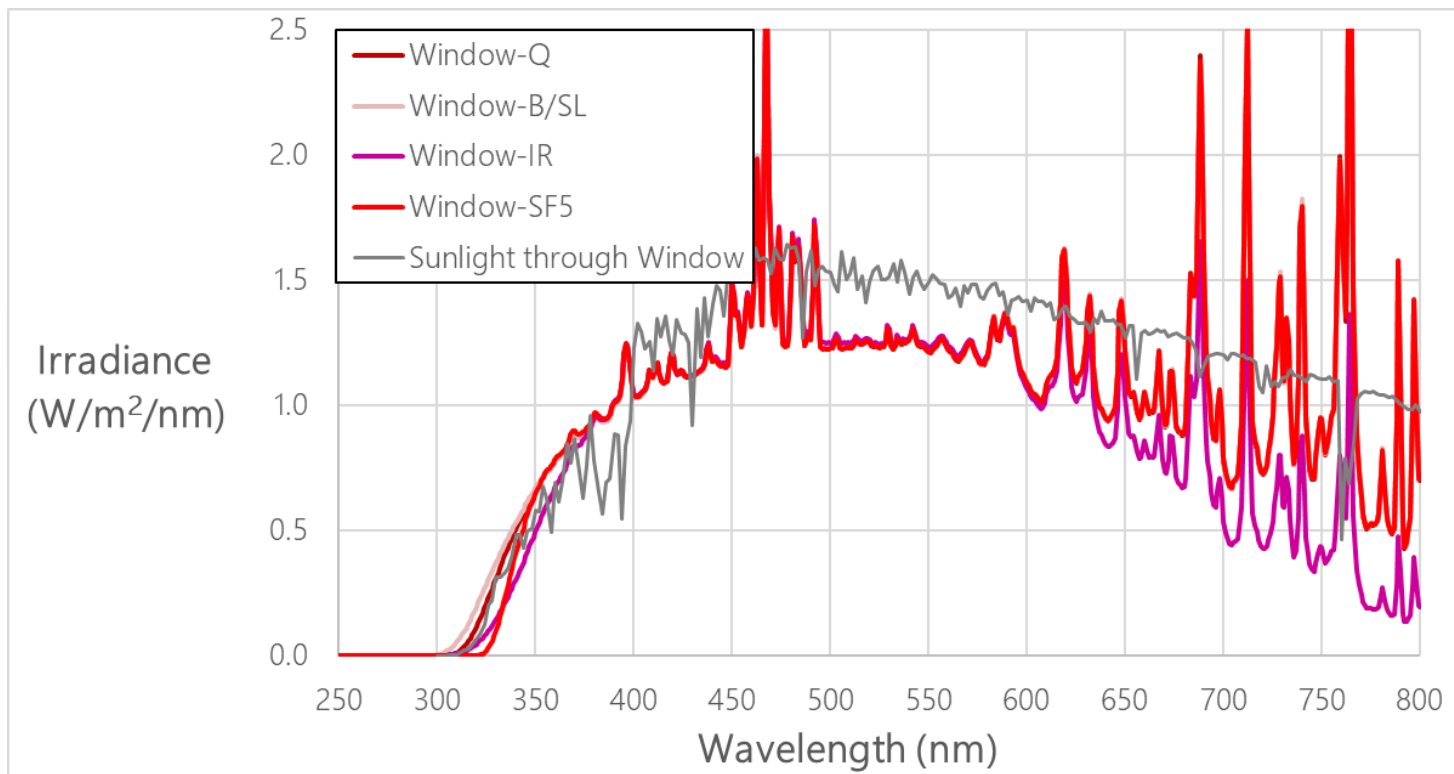


**Other specialized filters used occasionally*

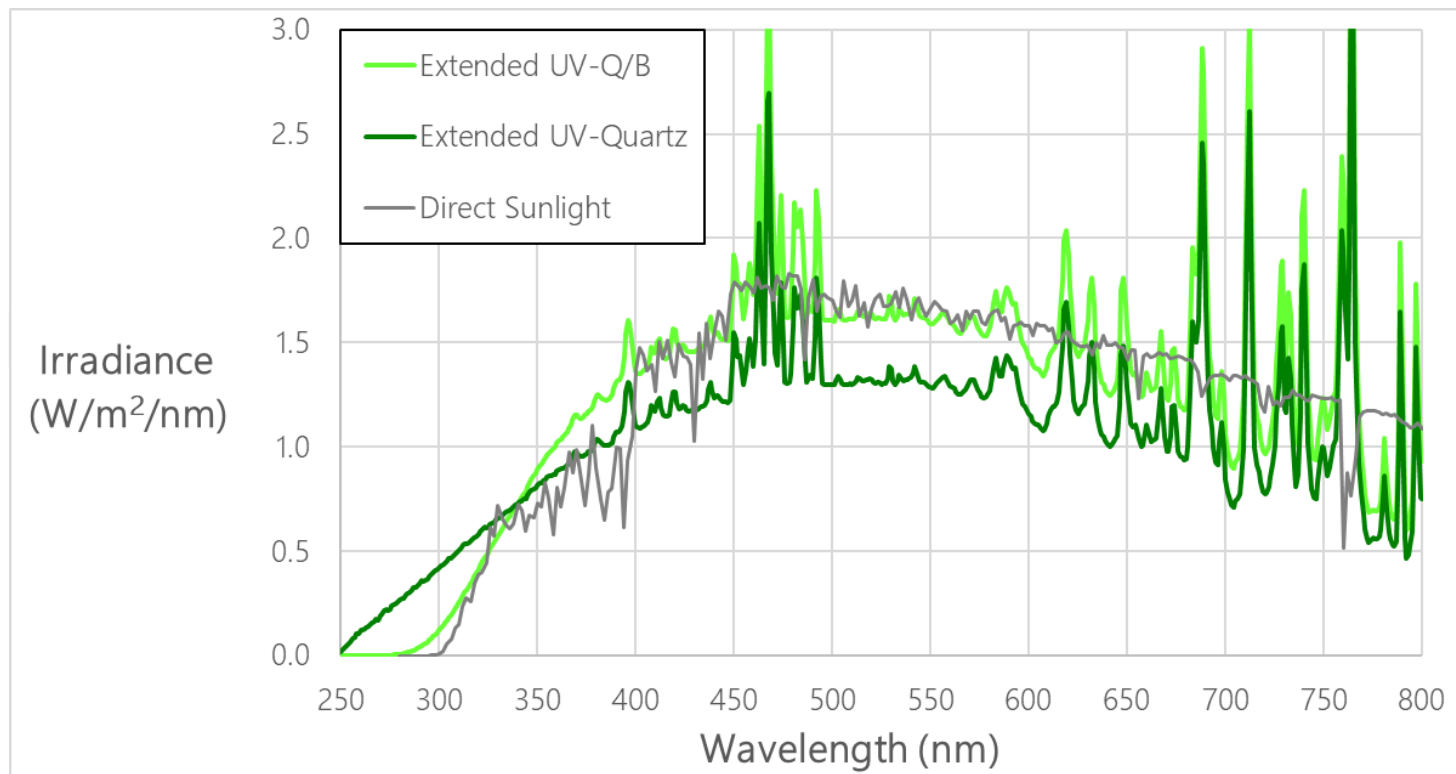
Daylight Filter Comparison 日光过滤片



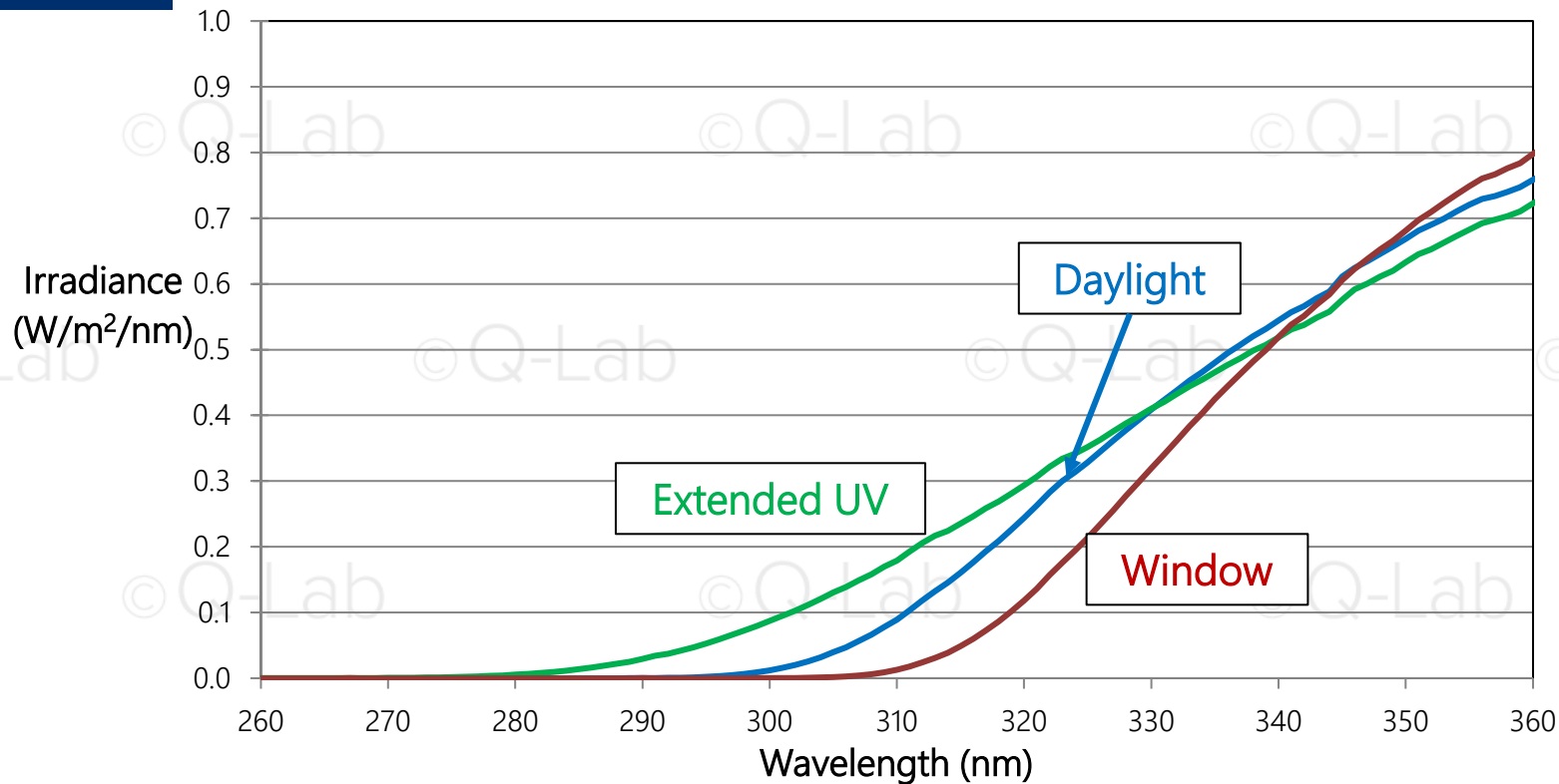
Window Filter Comparison 窗玻璃过滤片



Extended UV Filter Comparison 紫外延展过滤片



Optical Filters: UV Region 过滤片：紫外波段



Optical Filter Aging 过滤片老化

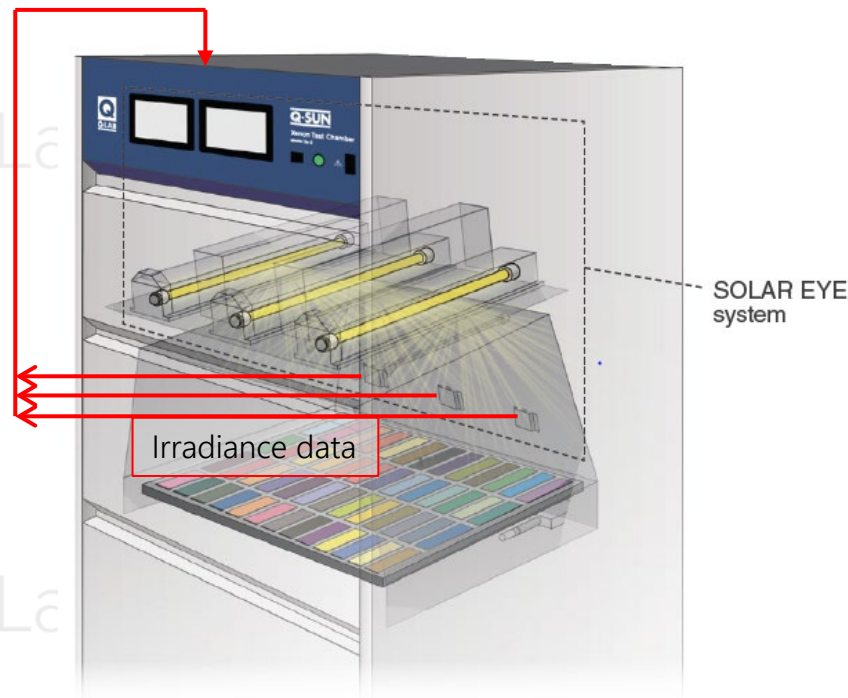
Water-Cooled vs Air-Cooled 水冷与风冷的比较

- Filters for water-cooled lamp systems need to be replaced every 400-2000 hours 水冷灯管系统的过滤片需要每400-2000h更换
 - Contaminants, even in ultra-pure de-ionized water, reduce filter transmittance over time 污染物会降低过滤片的透射率
- Almost all filters for air-cooled lamp systems do not age or need to be replaced 几乎所有风冷灯管系统的过滤片不会老化，无需更换

Q-SUN SOLAR EYE™

Irradiance Control 太阳辐照度控制

- Feedback Loop Control 闭环反馈
 - Xenon-arc lamp 氙灯
 - Light sensor 光探头
 - Control module 控制模块
- Wavelength at which irradiance is controlled is referred to as Control Point
- 控制辐照度的波长称为控制点



Irradiance Control Point Options 辐照度控制选择

- Narrow Band 窄带
 - 340 nm
 - 420 nm
- Wide Band 宽带
 - Total UV TUV (300-400 nm)
 - Global (300-800 nm) – not recommended 不推荐300-800控制
 - Shorter wavelengths cause more photodegradation 短波造成光老化
 - Fails to account for xenon lamp aging
 - 无法弥补灯管老化产生的问题

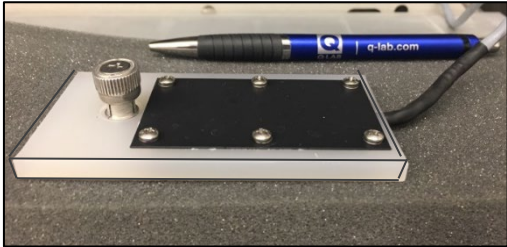
Why Is Choice of Control Point Important? 为什么控制点如此重要?

- Xenon Arc lamps age with use
- 随着使用氙灯会老化
- Spectral shift limits useful lamp life
- 光谱漂移限制了灯管寿命
- Controlling irradiance in **wavelength region of interest** maximizes repeatability and reproducibility
- 控制**关注波长区域**的辐照度可最大化测试可重复性和可再现性

Black Panel Temperature Control 黑板温度控制

- Most common in test standards
- 在测试标准中很普遍
- Approximates maximum specimen surface temperature
- 大概是样品表面的最高温度
- Can be used in combination with chamber air temp sensor and control
- 和箱体空气温度探头同时控制

Black Panel Temperature Sensors 黑板温度传感器

Panel	Construction	ASTM Designation	ISO Designation
 A photograph of an uninsulated black panel temperature sensor. It consists of a small, flat, black rectangular panel with a black cable attached. A blue pen with the Q-Lab logo is placed next to it for scale.	Black painted stainless steel	Uninsulated Black Panel 非绝缘黑板	Black Panel 黑板
 A photograph of an insulated black panel temperature sensor. It features a black rectangular panel mounted on a white, rectangular base. A black cable is attached to the side. A blue pen with the Q-Lab logo is placed next to it for scale.	Black painted stainless steel mounted on 0.6 cm white PVDF	Insulated Black Panel 绝缘黑板	Black Standard 黑标

* White Panel versions of the above are available but far less commonly used

To maximize acceleration, use maximum service temperature
为了最大化加速，使用最高工作温度

**To minimize error, *DO NOT* exceed
maximum service temperature**
为了减少误差，不要超过最高工作温度

Chamber Air Temperature Control 箱体空气温度控制

- Required by certain test methods
- 有些标准要求
- Necessary for control of relative humidity (RH)
- 湿度控制时候是需要空气温度控制的
- Sensor must be shielded from light
- 探头必须避光
- BP temp always hotter than chamber air temp from absorbing radiant heat
- 黑板温度在光照下大于空气温度

Relative Humidity Control 相对湿度控制

- Required by many test methods 很多测试需要湿度控制
 - Textiles 纺织
 - Automotive 汽车
- Many xenon testers can generate and control relative humidity
- 很多氙灯试验箱可以控制相对湿度
 - Boiler system 蒸汽系统
 - Nebulizer system 超声波系统
 - Air atomizing nozzle 空气雾化喷嘴
- For many durable materials, RH makes very little difference compared to spray and condensation
- 对很多耐候产品，相较于水喷淋和冷凝，湿度产生的作用很小

Xenon Arc Water Spray 氙灯水喷淋

Front spray 前喷

- Primary method of water delivery
- 水施加的主要方法
- Calibration technique for front spray recently developed (ASTM D7869)
- ASTM D7869对喷淋收集量的校准

Back spray 背喷

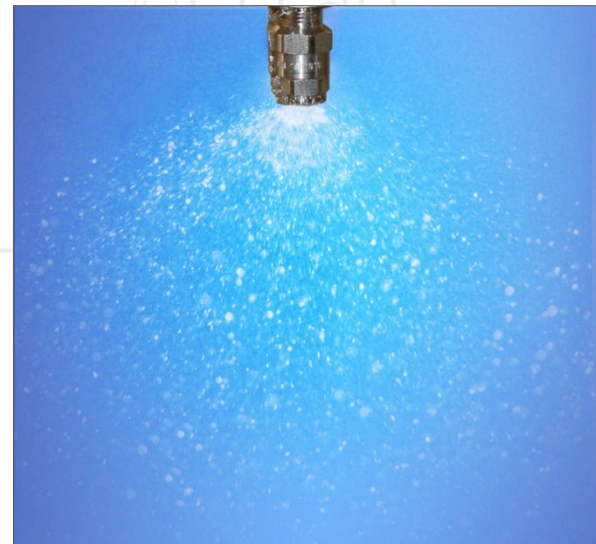
- Result of a failed experiment intended to generate condensation; persists in some standards
- 为产生冷凝而开发的失败实验，一些标准中存在

Dual spray 双喷淋

- For delivering a 2nd solution, e.g. acid rain, soap
- 施加第二种溶液，比如酸雨

Immersion (Ponding) 水浸

- Alternative to front spray called out in some standards
- 替代某些标准中规定的前喷淋



Xenon Arc Summary 氙灯测试总结

- Best simulation of full-spectrum sunlight
- 全光谱太阳光模拟
- Lamps experience aging (fulcrum effect)
- 灯管老化（支点效应）
- Temperature effects
- 温度影响
- Water spray and RH control
- 水喷淋和湿度控制
- Additional cost, maintenance, and complexity compared to fluorescent UV testers
- 和荧光紫外相比，成本较高，维护较复杂

Q-SUN Xenon Arc Testers Q-SUN氙灯试验箱

Xe-3



Xe-1



Xe-2

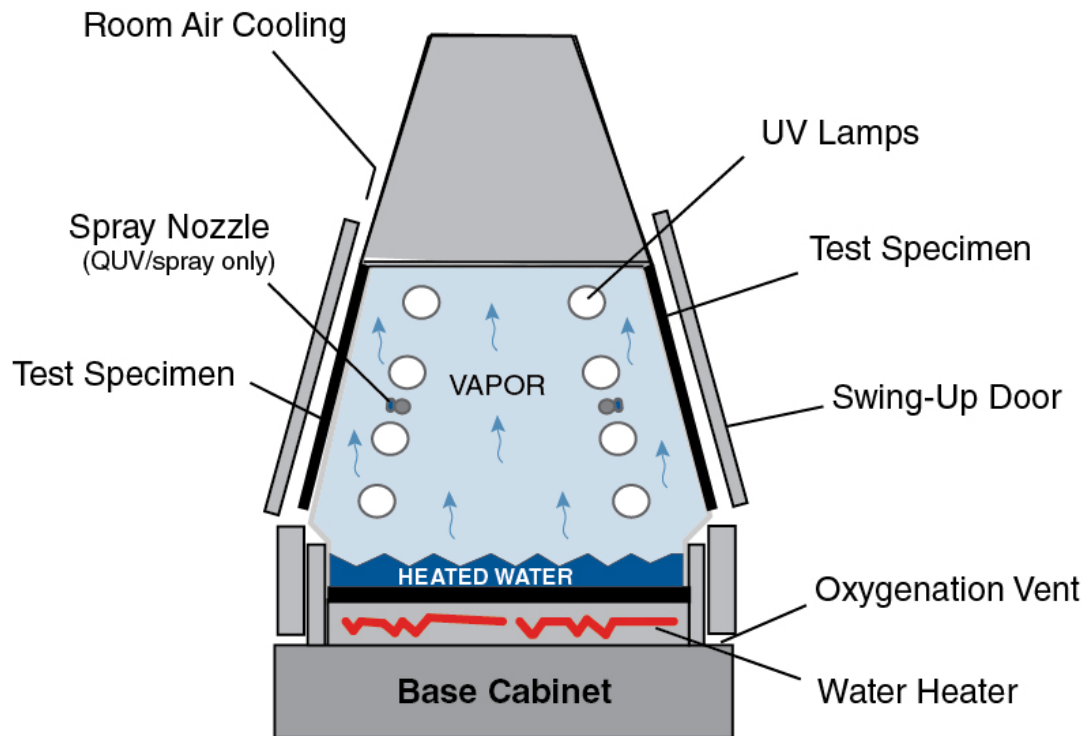


Xe-8



Fluorescent UV Laboratory Weathering 荧光紫外老化

Fluorescent UV Schematic 荧光紫外示意图

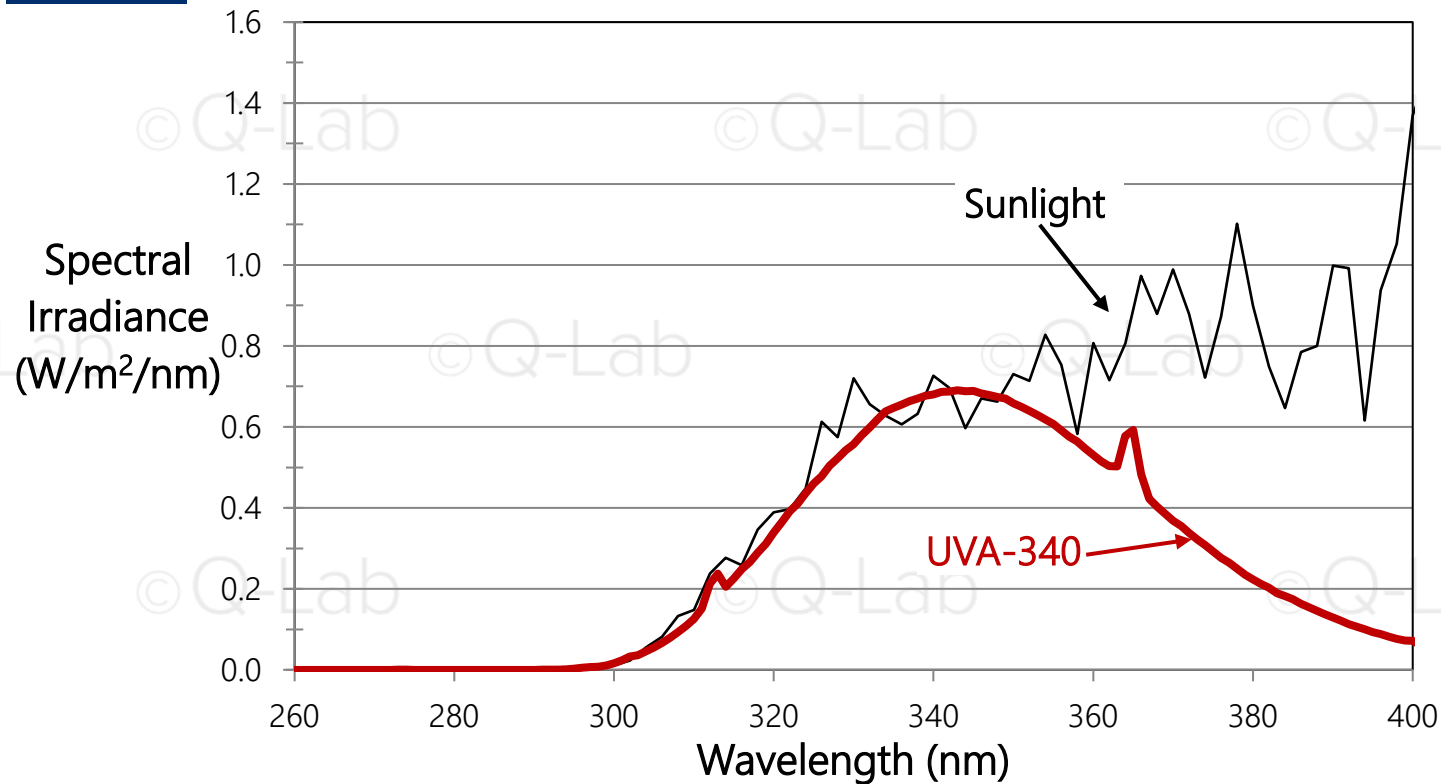


Fluorescent UV Lamps 荧光紫外灯管

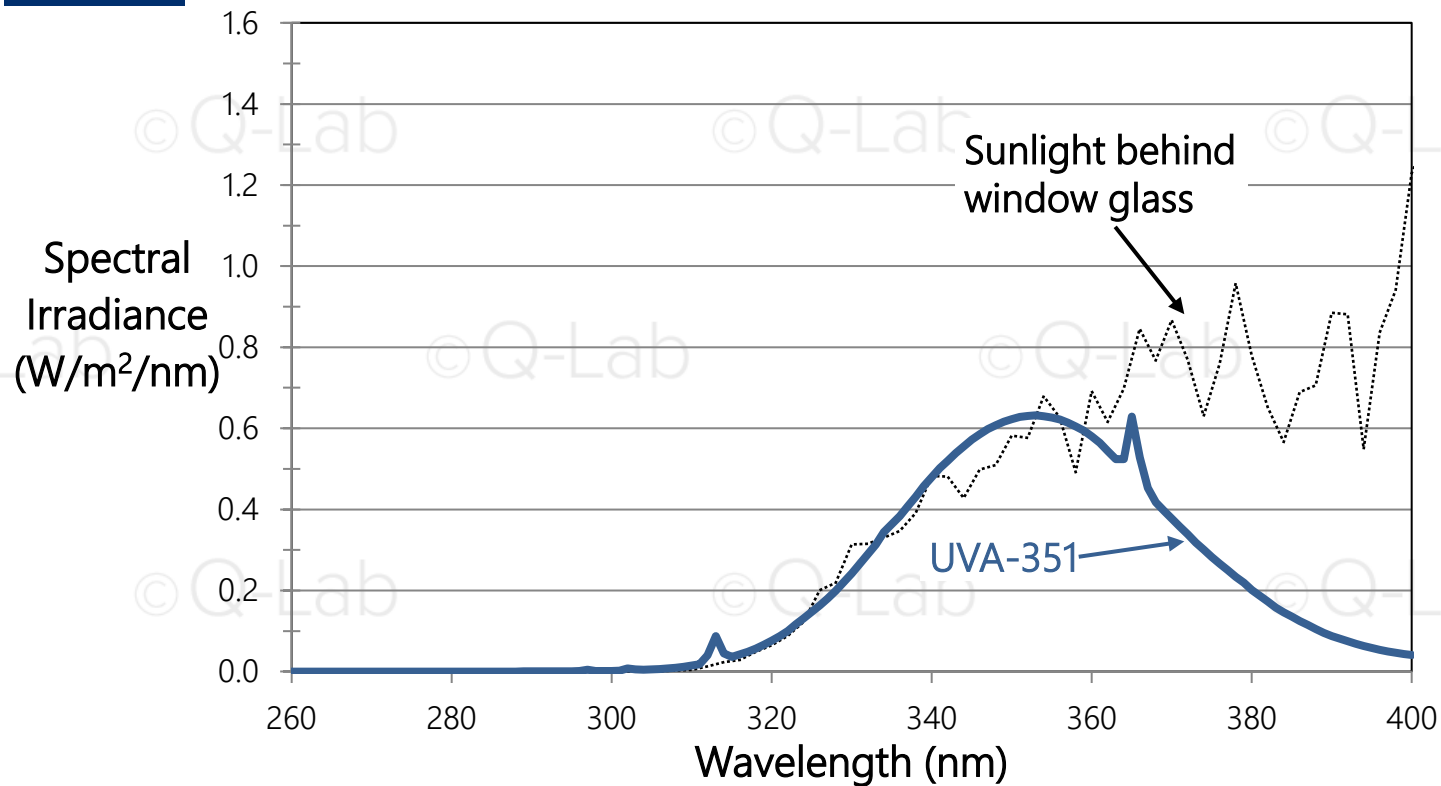
- UVA-340 (Daylight UV)
- UVA-351 (Window UV)
- UVB-313EL (Extended UV)
- UVC-254 (UVGI)
- TUV-421
- Cool White (Indoor, office)



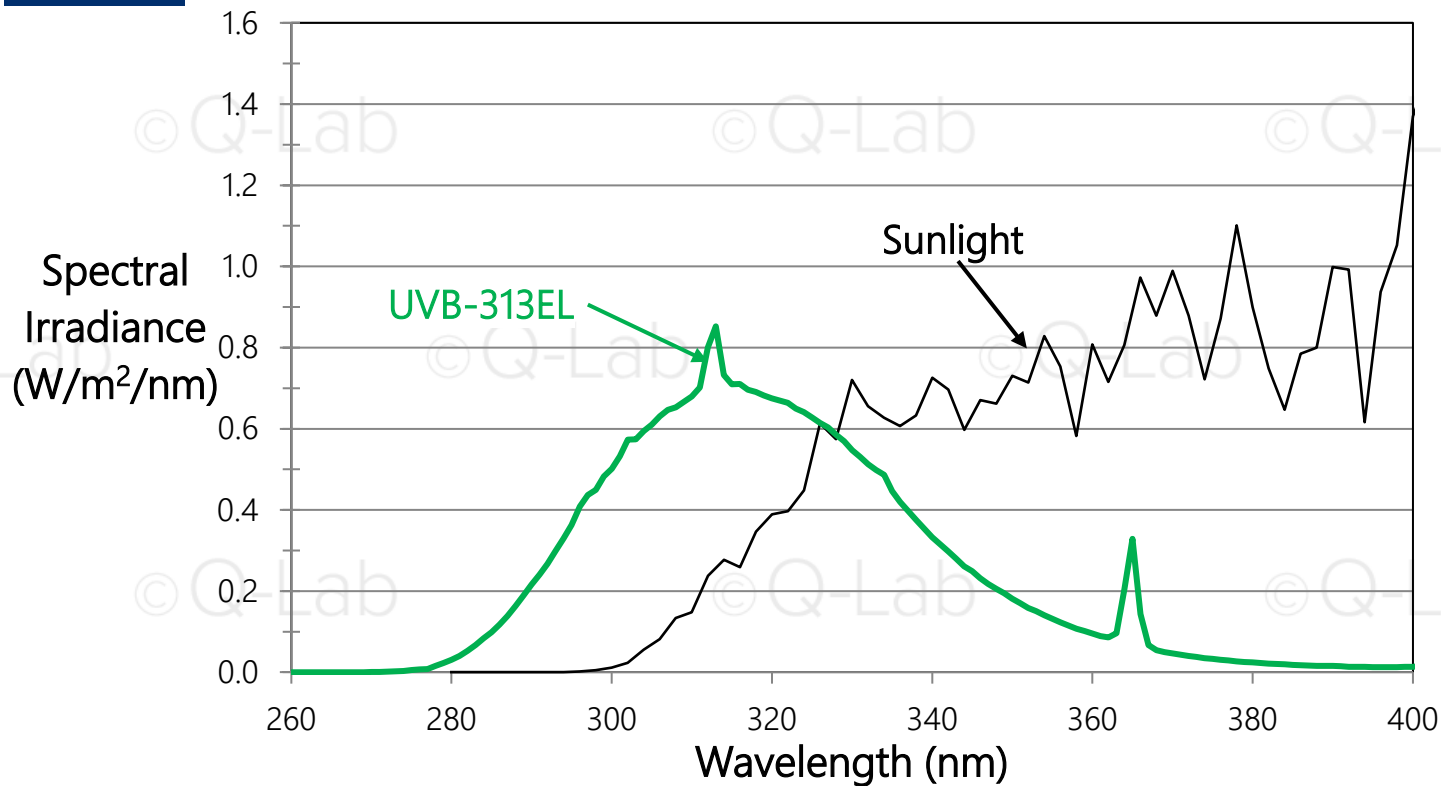
UVA-340 Lamps



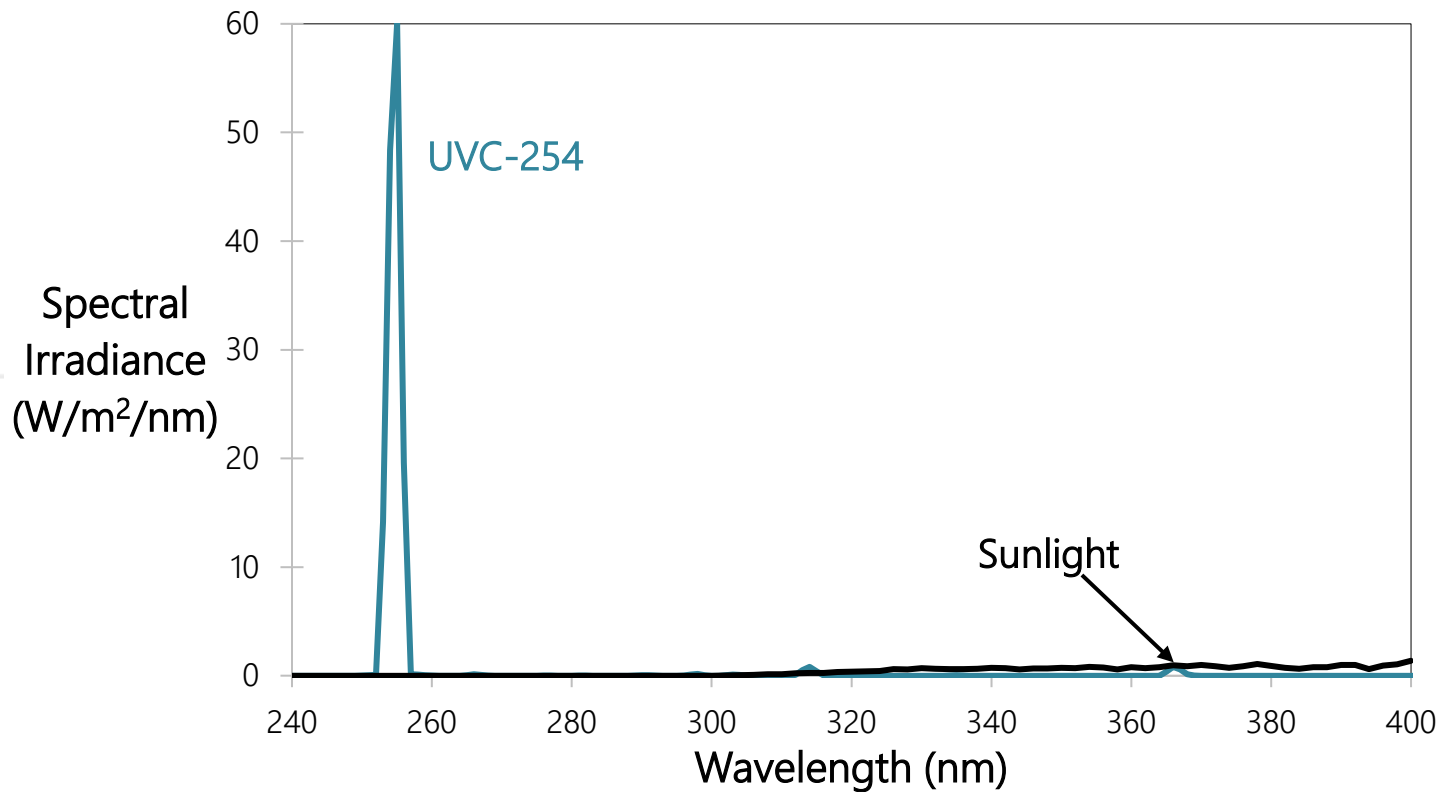
UVA-351 Lamps



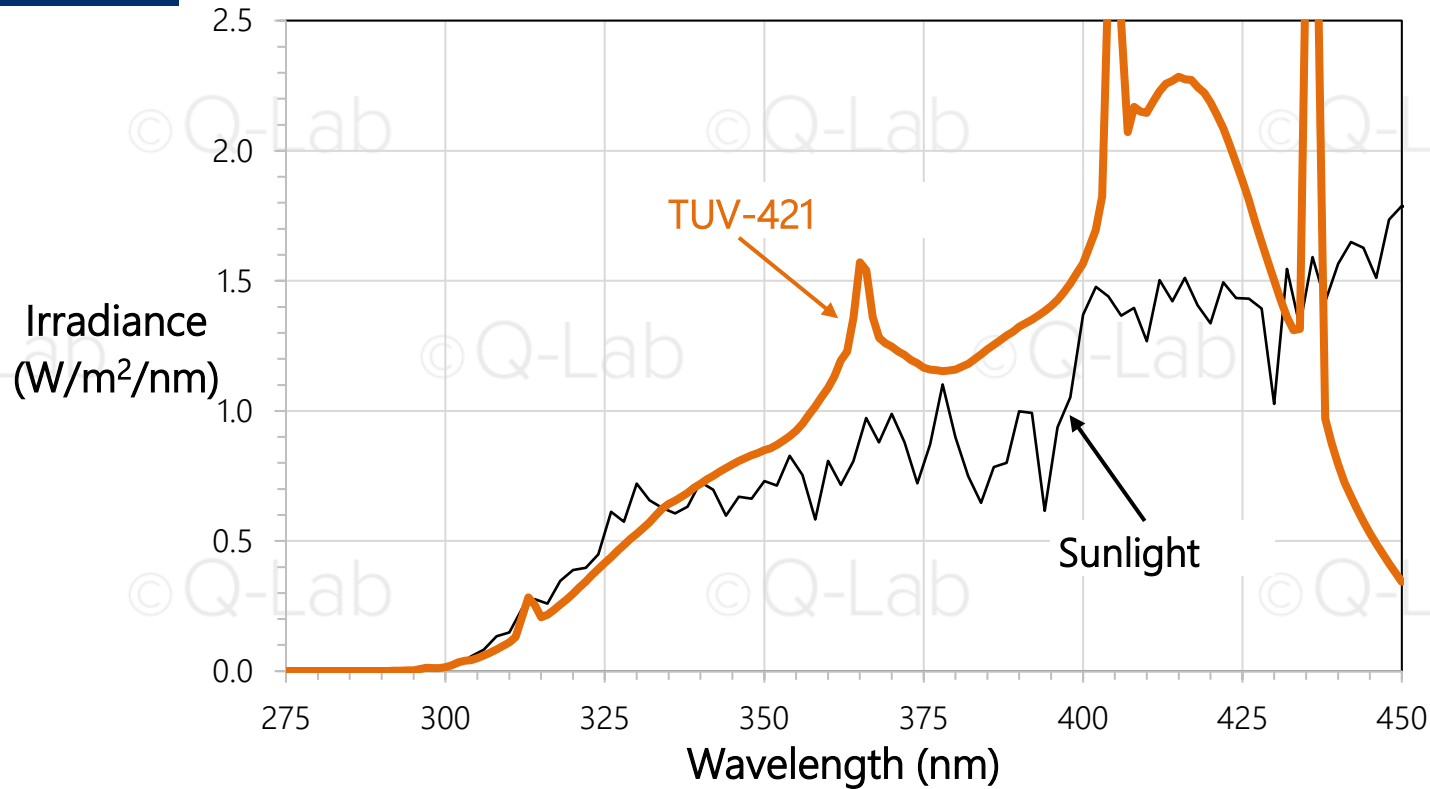
UVB Lamps



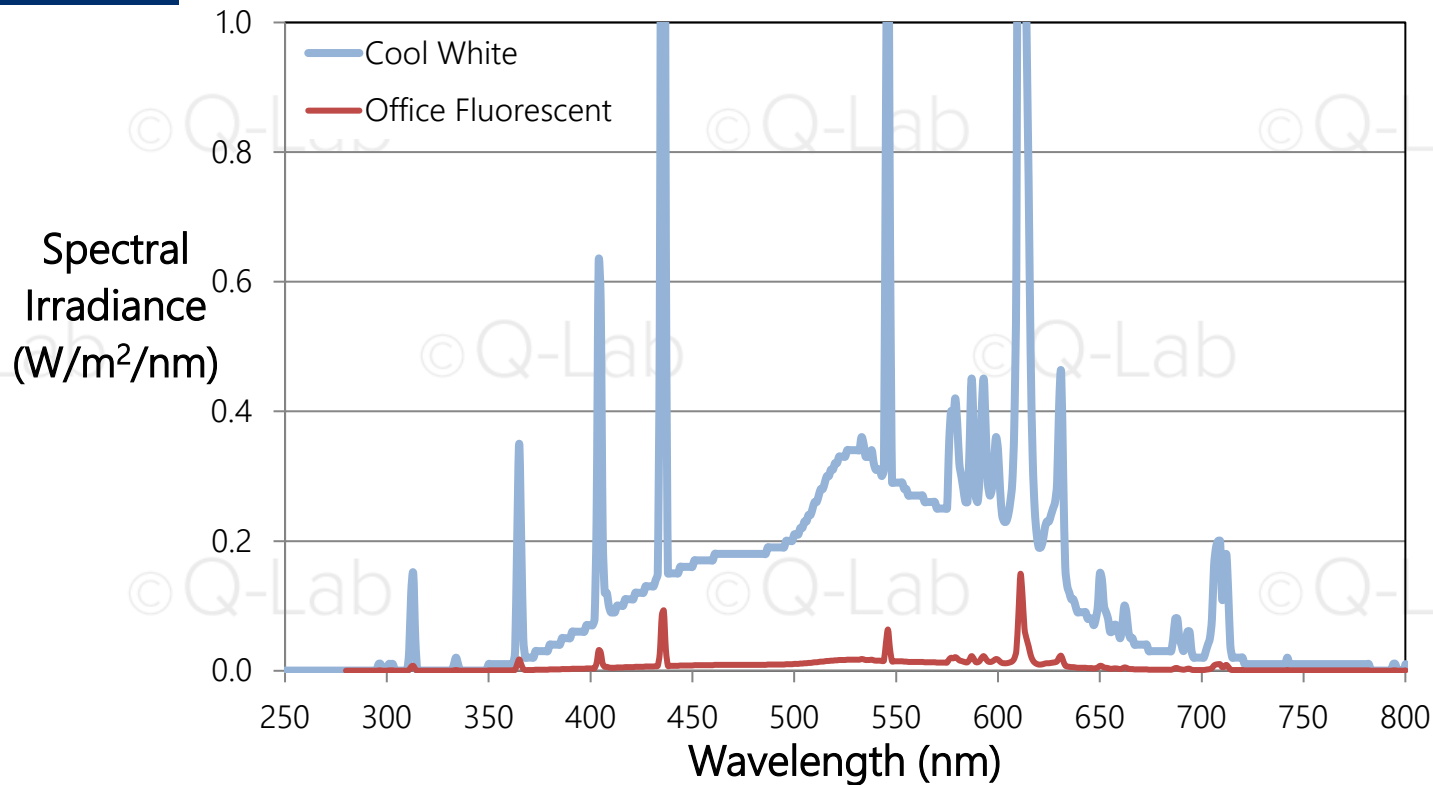
UVC Lamps



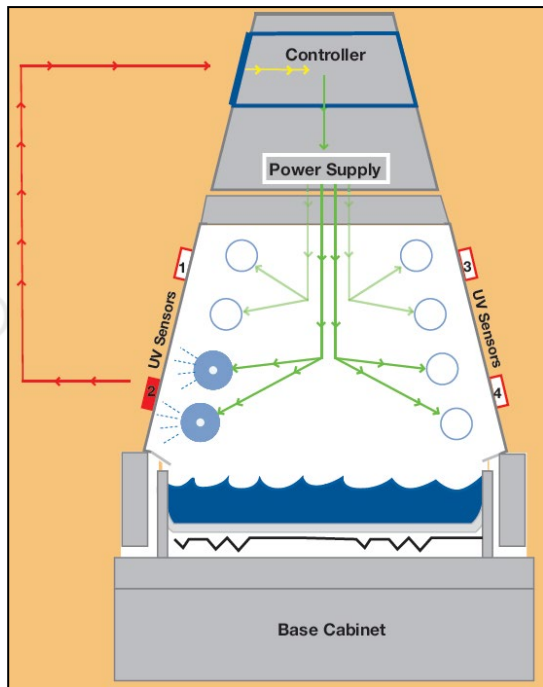
TUV-421 Lamps



Cool White Lamps



QUV SOLAR EYE™ Irradiance Control 太阳眼辐照度控制



Feedback Loop Control

闭环反馈控制

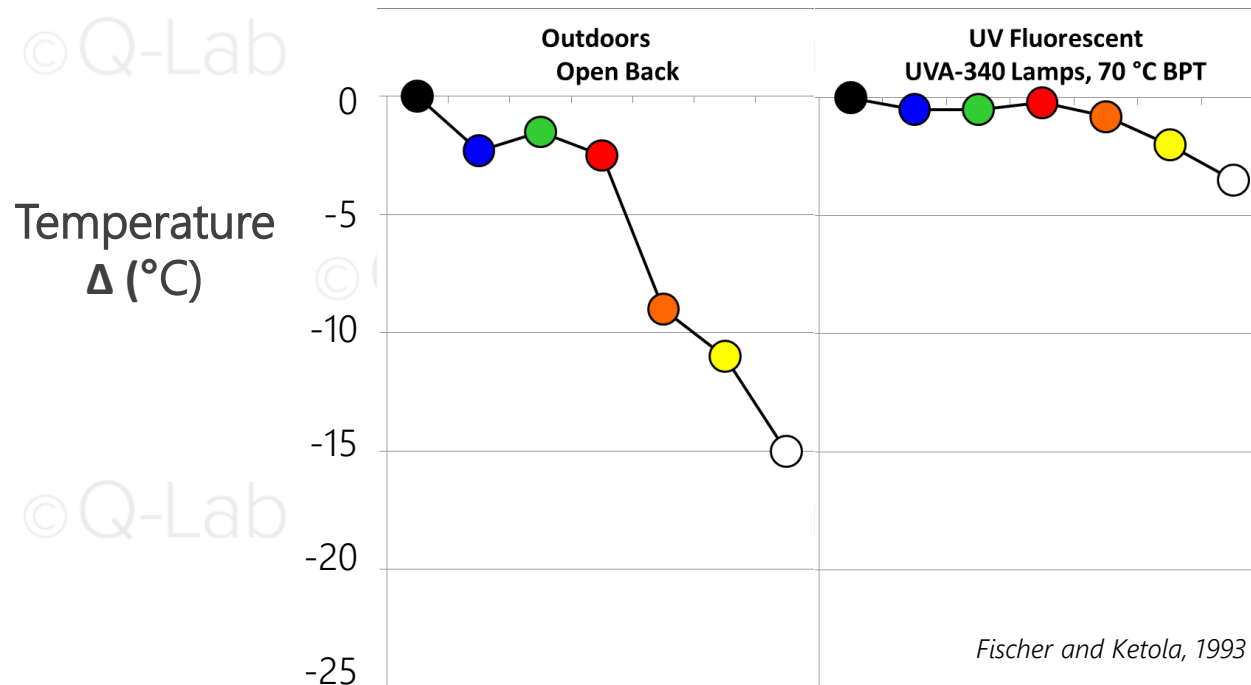
- Fluorescent UV lamp 紫外灯
- Light sensor 光探头
- Control module 控制模块

Fluorescent Lamp Advantages 荧光紫外灯优势

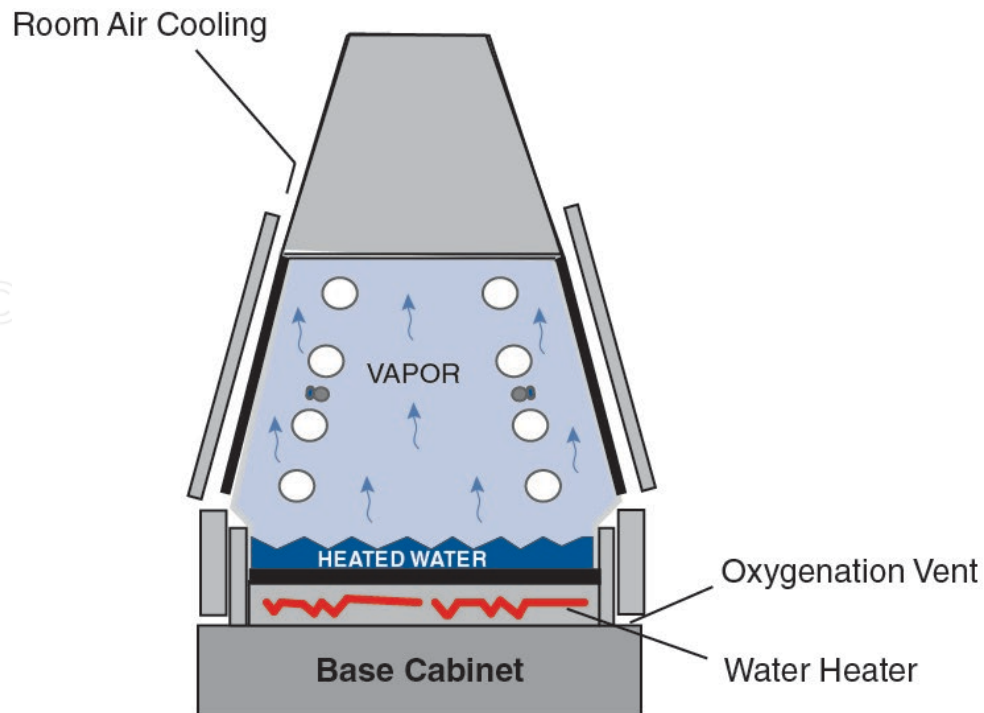
- Fast Results 更快得到结果
- Simplified irradiance control 简化辐照度控制
- Very stable spectrum – no aging 光谱稳定
- Low maintenance 低维护
 - Simple calibration 校准简单
- Low price and operating cost 低购机成本和运行成本
- Simple and easy to maintain 维护简单

Temperature & Color 温度和颜色

Temperature difference between colored panels and Black Panel



Condensation 冷凝



Condensation Advantages 冷凝优势

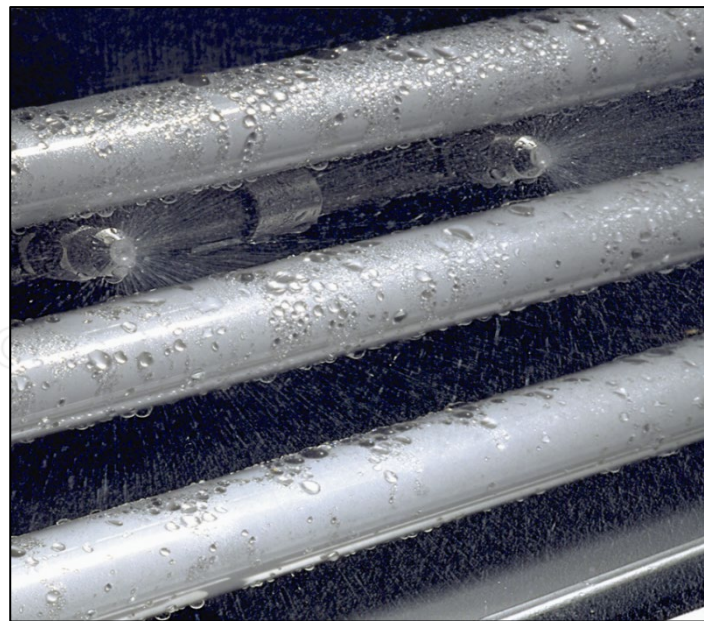
- Closest match to natural wetness
- 充分模拟户外潮湿
- Best way to accelerate water in an laboratory tester
- 实验室测试最好的水加速
- Elevated temperature
- 升温
- High O₂ content
- 高氧含量
- Tester performs distilling – you cannot deposit debris on specimens! Water is guaranteed to be clean.
- 样品表面无污染，冷凝产生蒸馏水



Creating condensation in the QUV is easy and does not require expensive, pure water

Water Spray 水喷淋

- Ensures that parts get fully saturated
- 保证样品充分水饱和
- Creates erosion & thermal shock
- 产生侵蚀和热冲击
- Less common than condensation
- 不如冷凝常见



QUV Specimen Mounting 试样安装



Fluorescent UV Summary 荧光紫外总结

- UVA-340 best simulation of short-wave UV UVA-340灯管最好地模拟短波紫外
- UVB-313 fastest & most severe UVB-313灯管老化测试快
- TUV-421 offers a broader spectrum for color fade TUV-421灯管提供宽波段光谱
- Stable spectrum – no aging 光谱稳定
- No visible light 没有可见光
- Condensation realistic & rigorous 冷凝真实模拟露水，充分潮湿
- Water spray available but not RH control 可以做水喷淋，但不能控制相对湿度

QUV Accelerated Weathering Tester QUV加速老化试验机



Fluorescent UV and Xenon Arc 荧光紫外和氙灯

Complementary Technologies 互补技术

Fluorescent UV

- UVA-340 best simulation of shortwave UV
- UVB-313 might be too severe
- TUV-421 lamps offer some visible
- Stable spectrum
- No RH control
- Condensation or water spray
- Inexpensive, simple to use

Xenon Arc

- Full spectrum (UV-Vis-IR)
- Best simulation of long wave UV & visible light
- Spectrum shifts
- RH control
- Water spray
- More complex system

What We Will Talk About 内容

- Basics of Weathering 老化机理
- Why Perform Laboratory Weathering? 为什么进行实验室加速老化？
- Laboratory Weathering Testing 实验室老化测试
 - Xenon 氙灯
 - Fluorescent UV 荧光紫外灯
- Elements of an Effective Testing Program 有效测试方案的要素

What Kind of Test Should I Run? 应该运行哪种测试?

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control 质量控制	Pass / fail 通过/失效	- Defined 确定的 - Short 短时间	Material specification 材料规格
Qualification / validation 验证	Pass / fail 通过/失效	- Defined 确定的 - Short 短时间	Reference material or specification 参比材料
Correlative 相关性	Rank-ordered data 排序相关	- Open-ended 不确定 - Medium 中等时间	Natural exposure (Benchmark site) 自然曝晒 (户外基准点)
Predictive 寿命预测	Service life Acceleration factor 加速因子	- Open-ended 不确定 - Long 长时间	Natural exposure (Service environment) 自然曝晒 (实际环境)

What Kind of Test Should I Run? 应该运行哪种测试?

Accelerated Test Type	Result	Test Time	Results compared to
Quality Control	Pass / fail	• Defined • Short	Material specification
Qualification / validation	Pass / fail	• Defined • Medium-long	Reference material or specification
Correlative	Rank-ordered data	• Open-ended • Medium	Natural exposure (Benchmark site)

Putting It All Together

- Identify the kind of accelerated test
- 辨别加速测试的目的
 - Outdoor data is imperative to correlative and predictive testing
 - 户外数据对于相关性研究和寿命预测至关重要
- Identify service environment
- 识别环境因素
 - Indoor or Outdoor 室内还是户外
 - Wet or Dry 潮湿还是干燥
 - Hot or Cool 热或冷

Putting It All Together

- Use Best Practices 最佳实践
 - Run until a defined failure mode 一直测试到定义的失效模式出现
 - Use multiple replicates 使用重复样
 - Perform evaluations and reposition frequently 定期评估和轮换样品位置
- Pick an appropriate Test Architecture 选择适当的测试体系结构
 - What does the standard say? 标准怎么说？
 - Is full spectrum important? 全光谱重要吗？
 - How important is water uptake? 水施加有多重要？

Thank you for your attention!

Questions?

Send your inquiry to:
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Q-Lab中国微信公众账号: 耐候腐蚀设备及测试专家

- ✓ 技术研讨会、网络研讨会信息
- ✓ 老化及腐蚀技术文章、最新测试标准解读等
- ✓ 相关技术问题，也可通过平台留言，我们会在24小时内和您联系

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