Accurate Measurement of Transmittance and Reflectance for Engineering Applications

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Façade & Roof Materials Testing Laboratory

OTM Solutions Pte Ltd

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ilac-MRA

ACCREDITED LABORATORY
SAC-SINGLAS
Cert No: LA-2016-0610-G

OTM
Optical & Thermal Measurement

About OTM Solutions Pte Ltd

A company providing optical & thermal measurement solutions

Laboratory testing

- Glass optical & thermal properties
- Daylight reflectance
- Solar reflectance & absorptance
- Transparent material haze
- Color & color difference
- Gloss
- Emissivity
- Spectral transmittance & reflectance

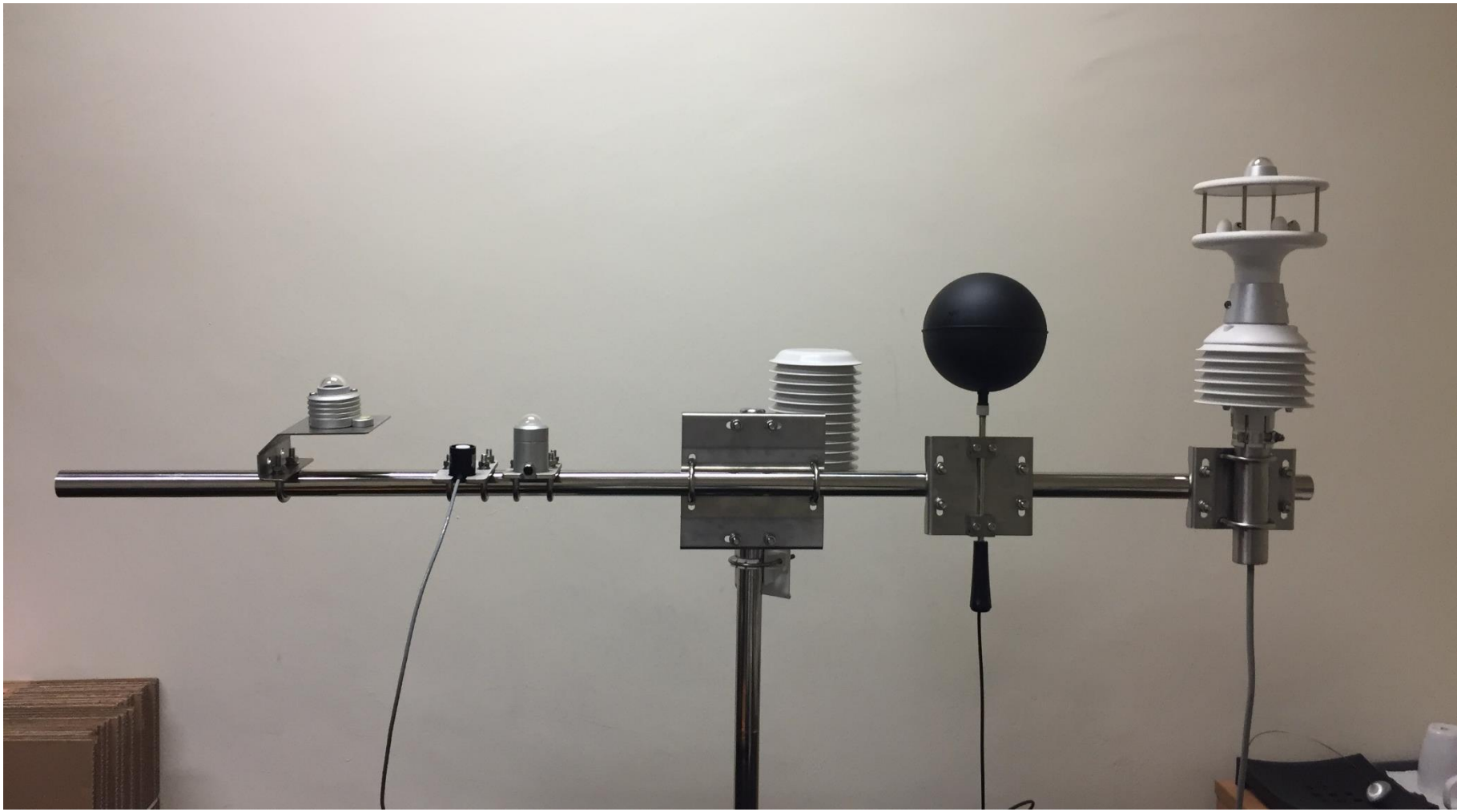
On-site testing

- Color and gloss uniformity
- U-value

On-site monitoring

- Temperature, heat flow, solar irradiance, daylight illuminance, noise

On-site monitoring



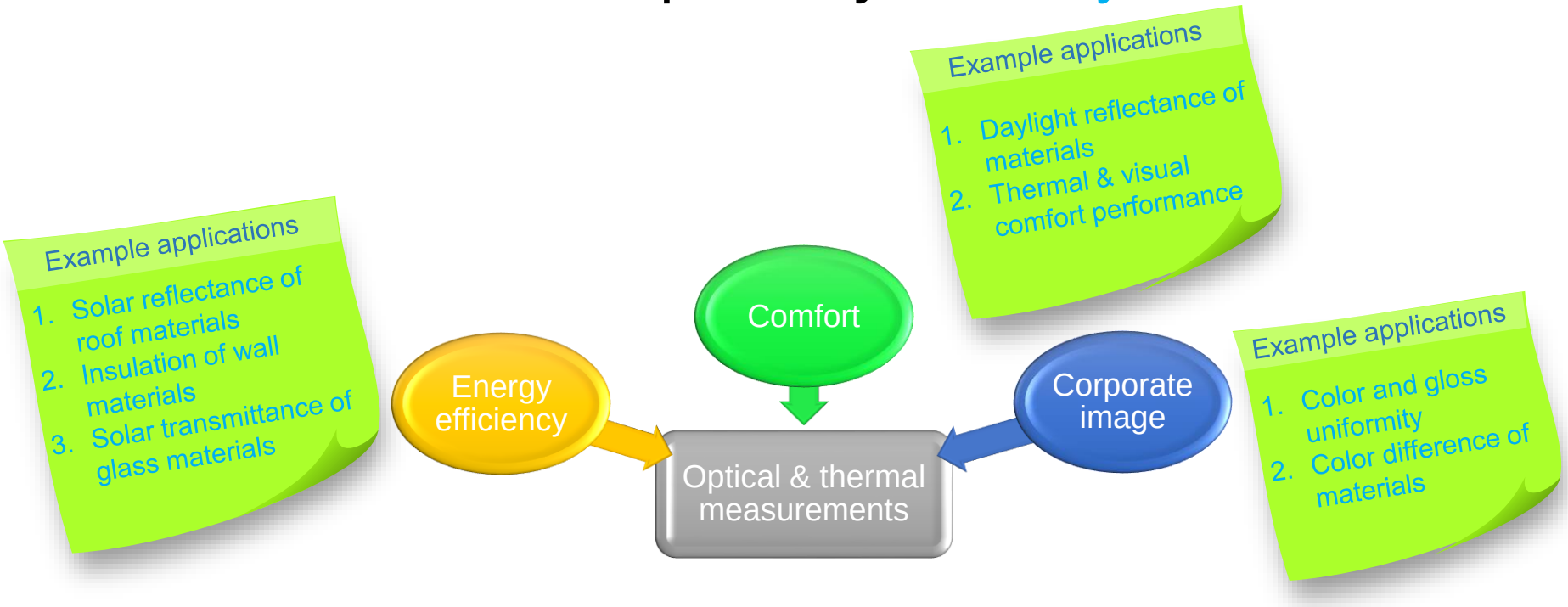
- Micro-climate: thermal comfort, solar irradiance, daylight illuminance

Instrumentation

- For users who want to own the instruments

Why optical & thermal measurements?

- Our services are inspired by industry's demands



- We are engaged, when
  - ➢ Third-party endorsement is required
  - ➢ In-house capabilities are not available

Presentation outline

- PerkinElmer instruments used in our laboratory
- Optical properties measured
- Optical and thermal properties calculated
- Our laboratory practices

Lambda 950 UV/VIS/NIR spectrophotometer

- Wavelength range: 250 nm – 2500 nm
  - Typical solar spectrum range: 300 nm – 2500 nm
- With 150 mm integrating sphere
- PbS detector for the NIR range

Spectrum Two FTIR spectrometer

- Wavelength range: 5 μm – 25 μm (or 2000 cm^{-1} – 400 cm^{-1}, in wavenumber)
- With Pike Spec10 accessory
  - For 10° specular reflectance measurement

Presentation outline

- PerkinElmer instruments used in our laboratory
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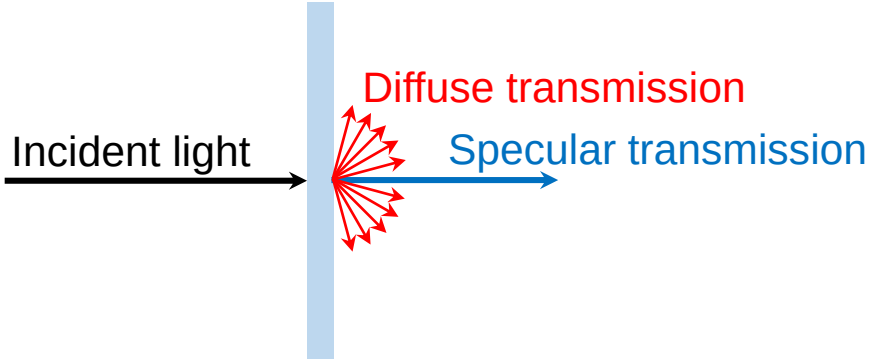
- Our laboratory practices

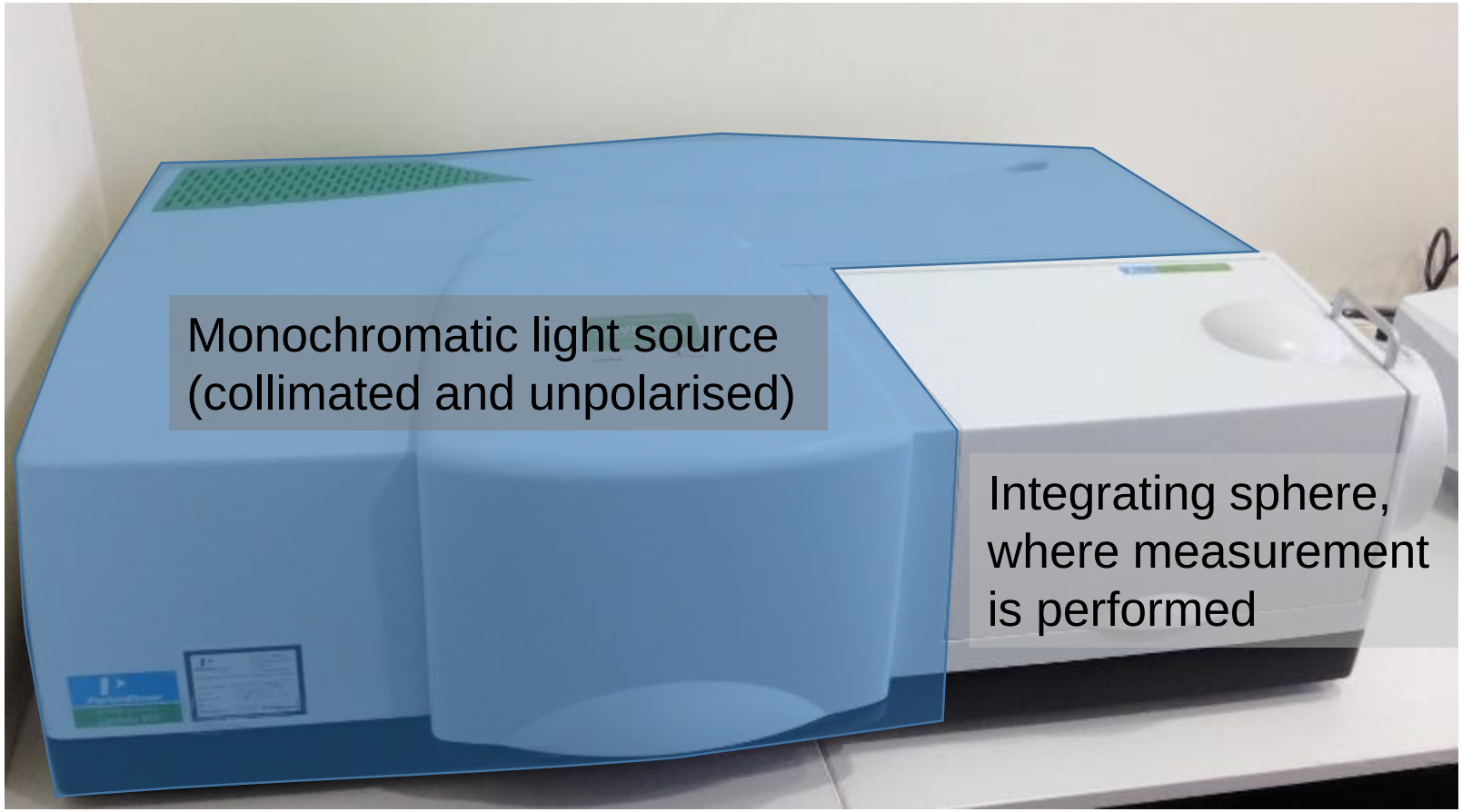
Transmittance measurement by UV/VIS/NIR



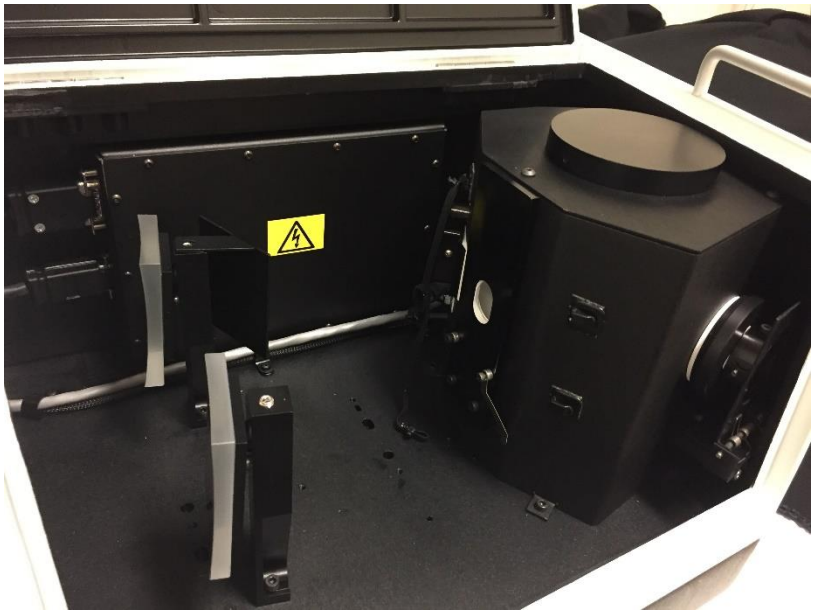
- Spectral transmittance
  - Total (specular component included, SCI)
  - Diffuse (specular component excluded, SCE)
- Incident angle is normal

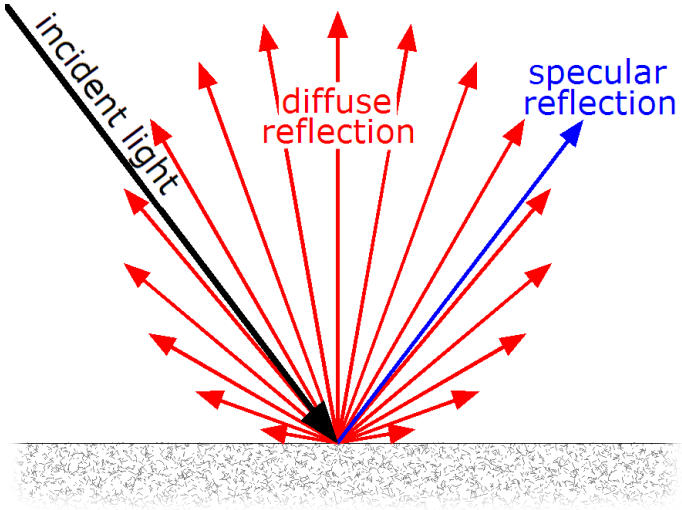
- Transmittance is a ratio (dimensionless), in the range of 0 – 1 (or 0% - 100%)

Transmittance measurement by UV/VIS/NIR



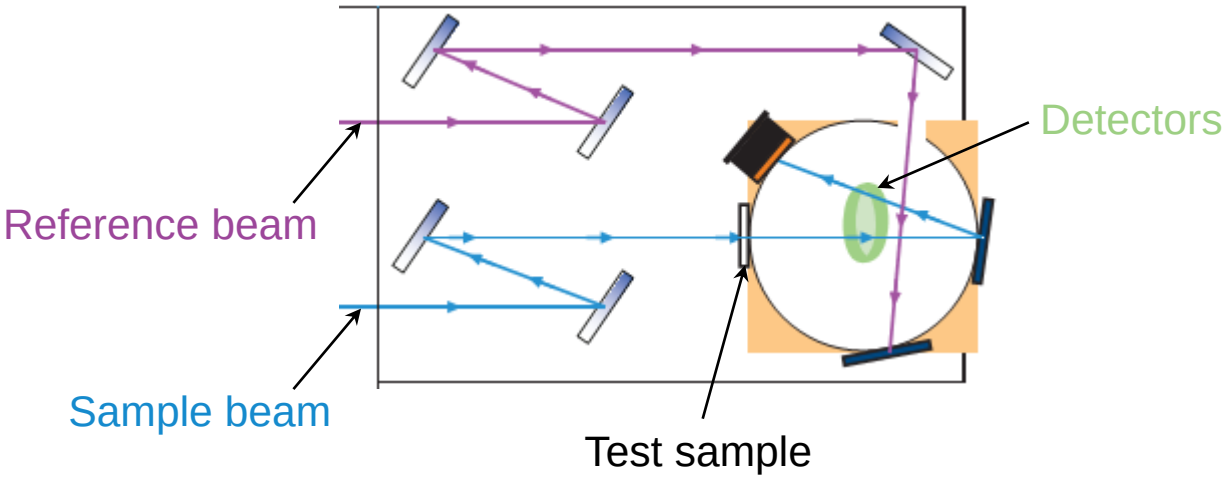
Integrating sphere





- Integrating sphere: an optical device integrate (or average) all specular and diffuse radiation
  - Without it, measurement is angle dependent

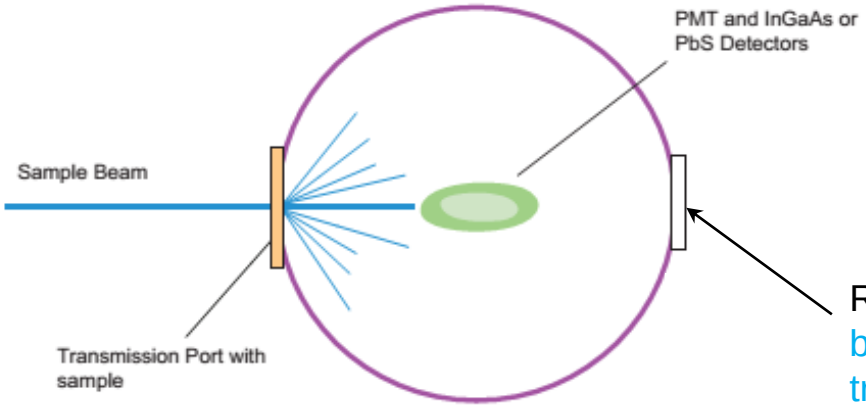
Transmittance measurement principle



- Auto-zero (calibration)
  - 100%T baseline (no test sample)
  - 0%T baseline (sample beam blocked)
- Sample transmittance measurement
  - Transmittance is calculated with linear interpolation

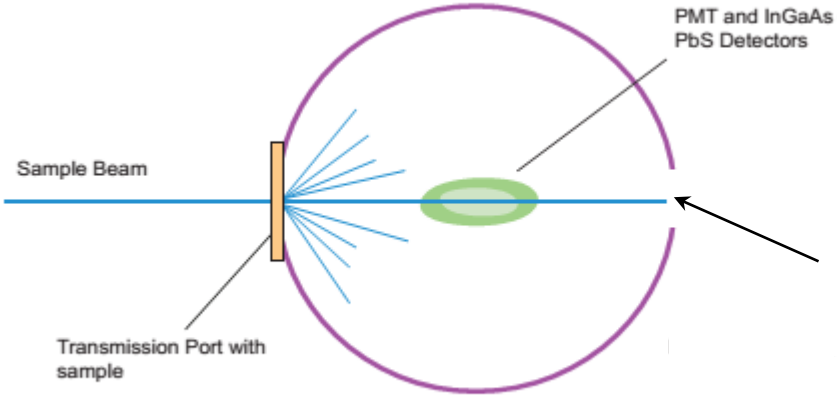
- Reference & sample beams are monochromatic (i.e. spectrally resolved); detectors do not resolve spectrum

Transmittance measurement principle



Reflectance port is covered, both specular and diffuse transmissions are detected

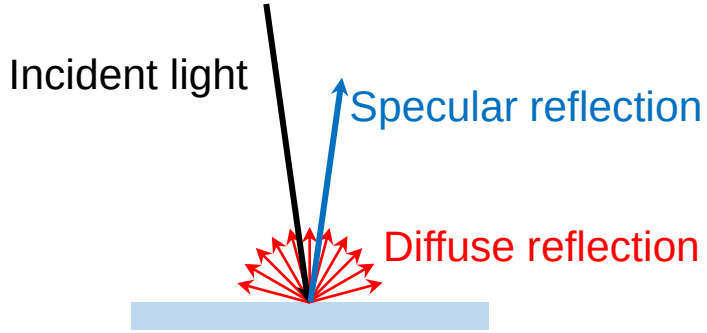
Total transmittance measurement



Reflectance port is open, only diffuse transmission is detected

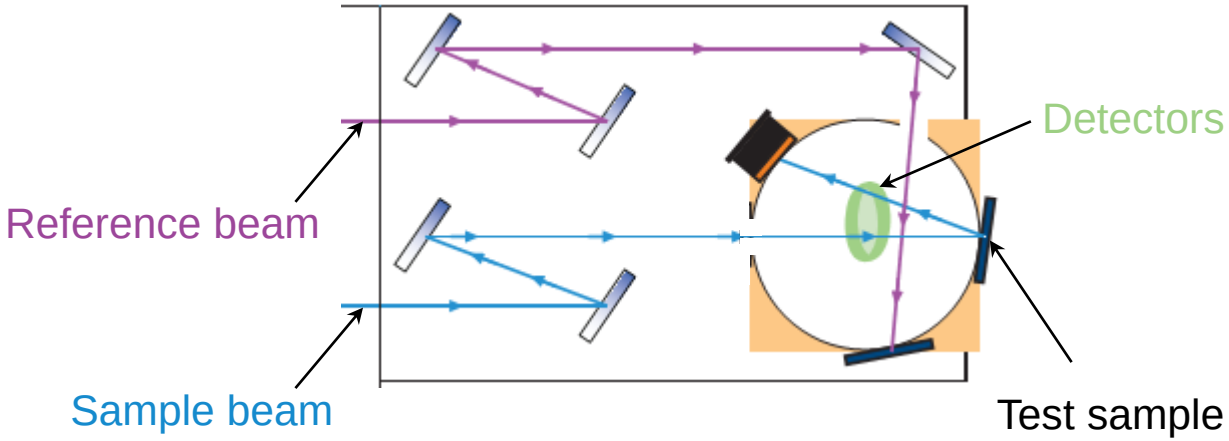
Diffuse transmittance measurement

Reflectance measurement by UV/VIS/NIR



- Spectral reflectance
  - Total (specular component included, SCI)
  - Diffuse (specular component excluded, SCE)
- Incident angle is near-normal (8°)
- Reflectance is a ratio (dimensionless), in the range of 0 – 1 (or 0% - 100%)

Reflectance measurement principle

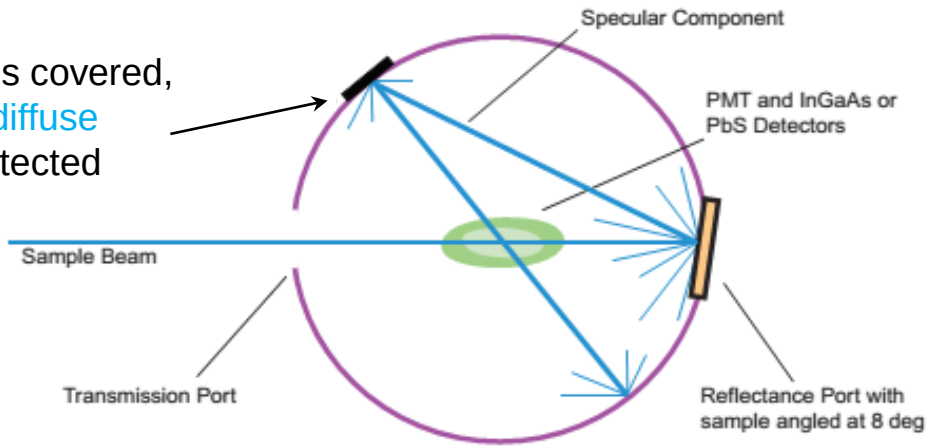


- Auto-zero (calibration)
  - 100%R baseline (nominally 100%R, with calibrated reflectance reference, e.g. spectralon)
  - 0%R baseline (with light trap)
- Sample reflectance measurement
  - Reflectance is calculated with linear interpolation, corrected by 100%R reference material reflectance

Spectralon reference material

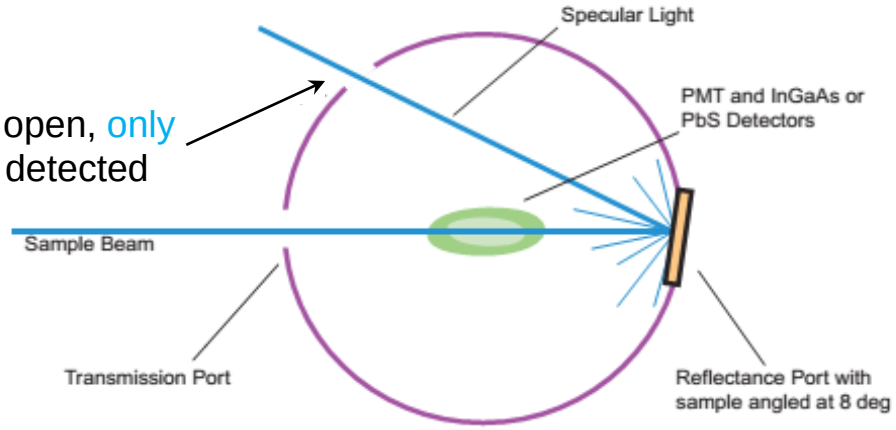
Reflectance measurement principle

Specular light port is covered, both specular and diffuse reflectances are detected



Total reflectance measurement

Specular light port is open, only diffuse reflectance is detected



Diffuse reflectance measurement

Presentation outline

- PerkinElmer instruments used in our laboratory
- Optical properties measured
- Optical and thermal properties calculated
- Our laboratory practices

Optical and thermal properties calculated

Measured by instrument

Spectral transmittance & reflectance
- Total or diffuse

Required by industry

Glass & transparent materials
- Visible light transmittance & reflectance
- Solar energy transmittance & reflectance
- UV transmittance
- U-value & shading coefficient
- Color
- Haze

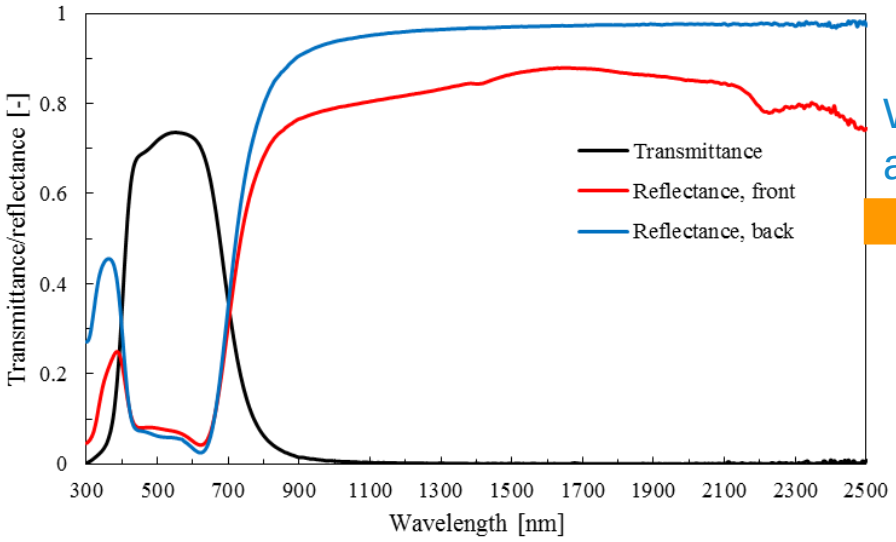
General materials
- Daylight reflectance
- Color

Roof materials
- Solar reflectance
- Solar reflectance index (SRI)

Optical materials
- Spectral transmittance & reflectance

From spectral properties to broadband properties

Spectral properties

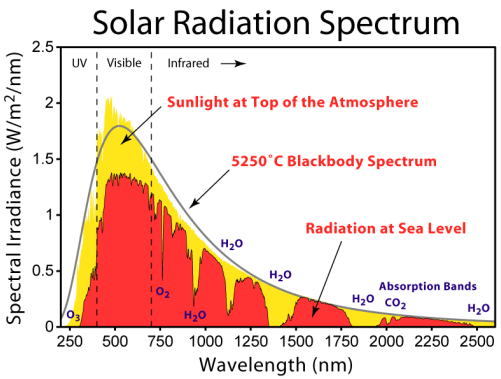


Weighted averaging

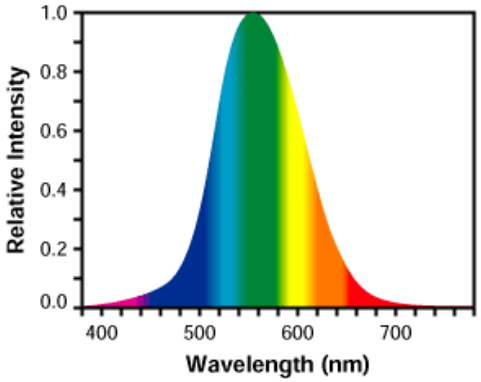
Broadband properties

Solar energy transmittance & reflectance
Visible light transmittance & reflectance
Tristimulus values (color)

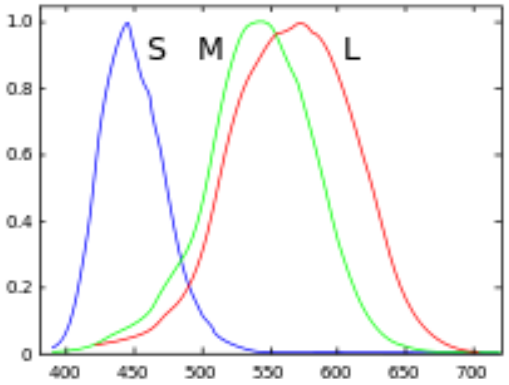
Weights



For solar energy

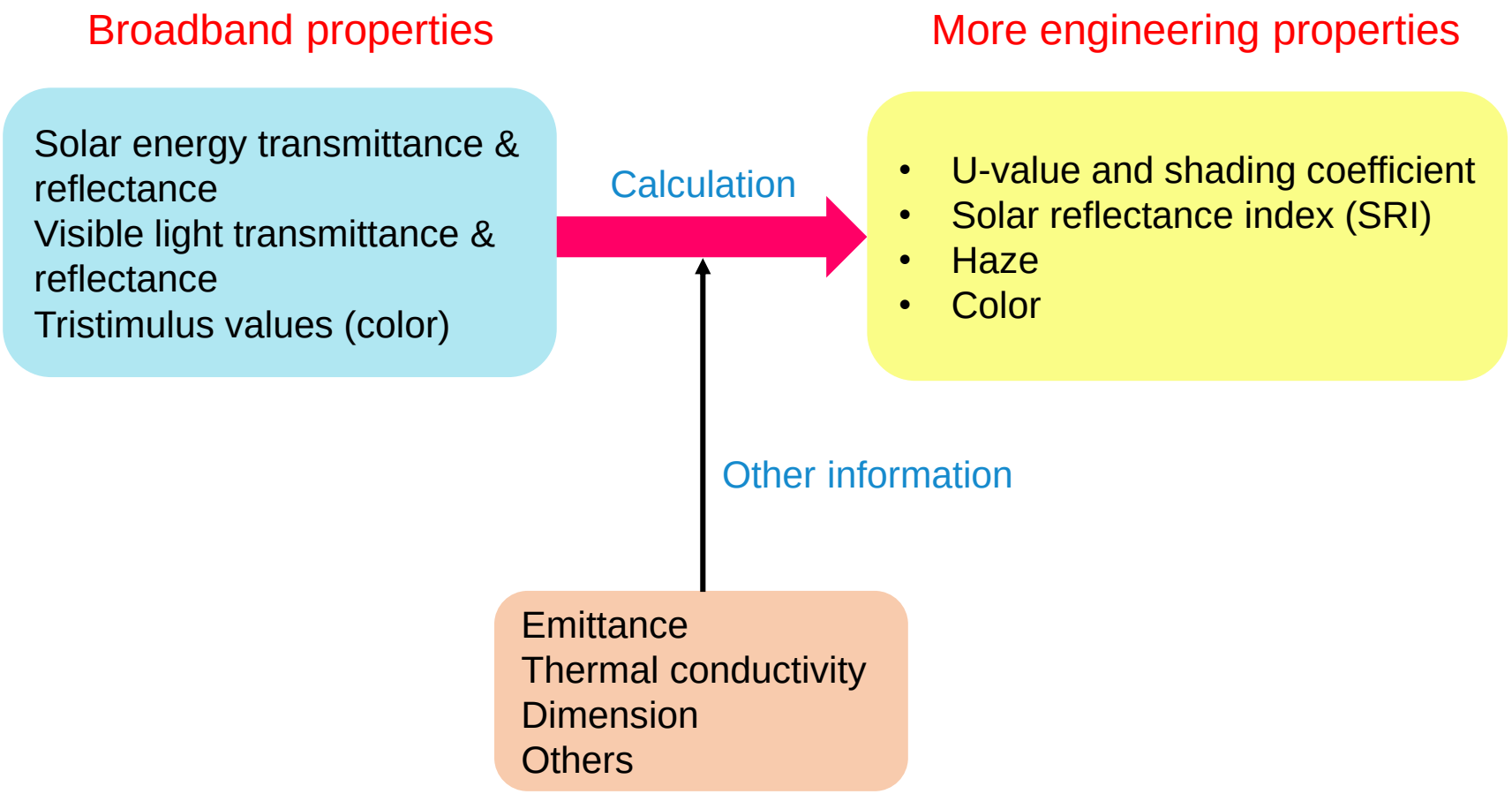


For visible light

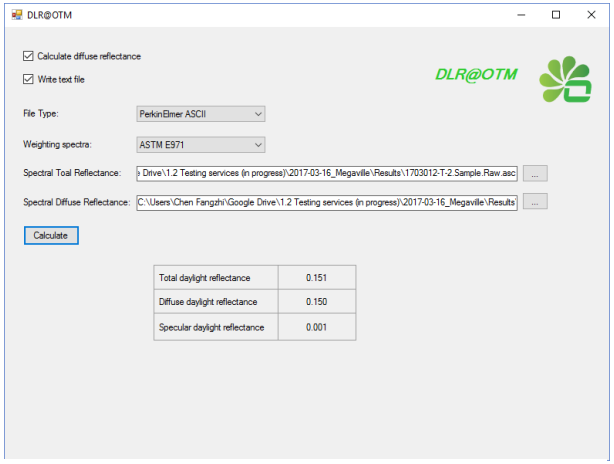


For color

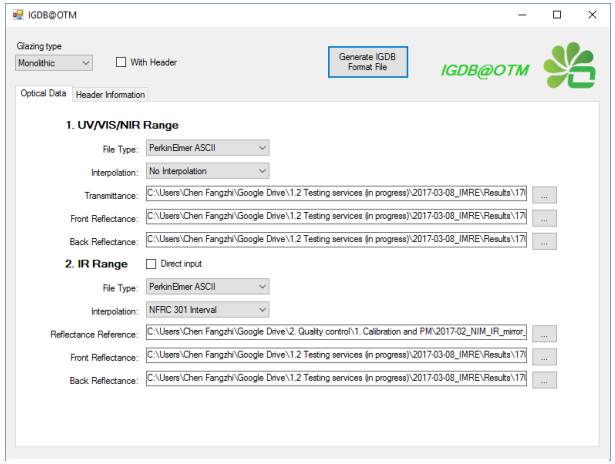
From broadband properties to more engineering properties



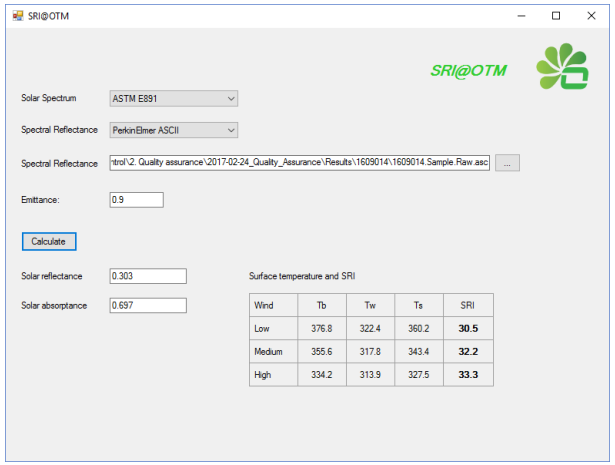
In-house calculation tools



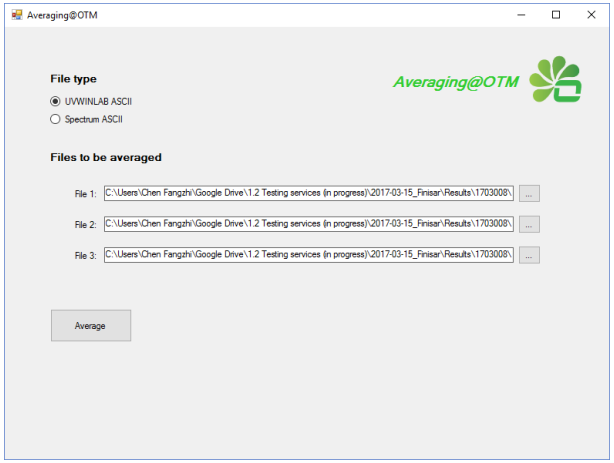
DLR@OTM
For daylight reflectance calculation



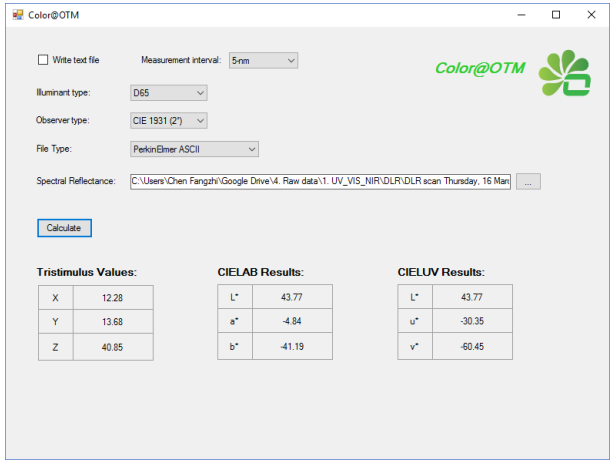
IGDB@OTM
For IGDB file generation



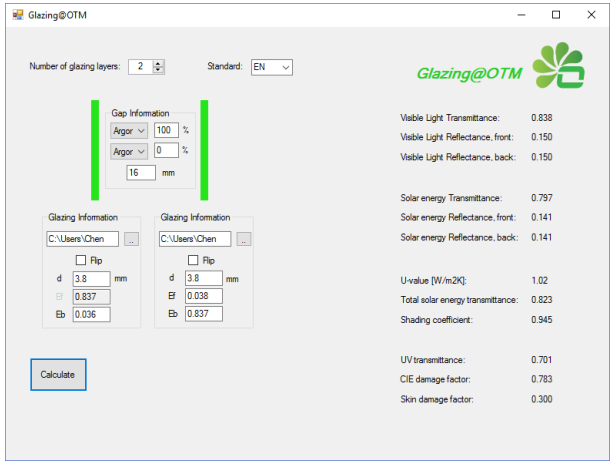
SRI@OTM
For solar reflectance index calculation



Averaging@OTM
For result averaging



Color@OTM
For color calculation



Glazing@OTM
For glass calculation

Presentation outline

- PerkinElmer instruments used in our laboratory
- Optical properties measured
- Optical and thermal properties calculated
- Our laboratory practices

Our laboratory practices

Equipment

Accommodation environment

Staff competence

Measurement uncertainty

Quality assurance

ISO 17025

Equipment

- Our critical vendor evaluation system evaluates five factors
  - 1. Quality
  - 2. Lead time
  - 3. Responsiveness
  - 4. Warranty and services
  - 5. Cost

- The weightage of quality is 2 times of the others

- PerkinElmer instruments were selected mainly because
  - Popularity in the transmittance and reflectance measurement community
  - Responsive and knowledgeable local support

Equipment

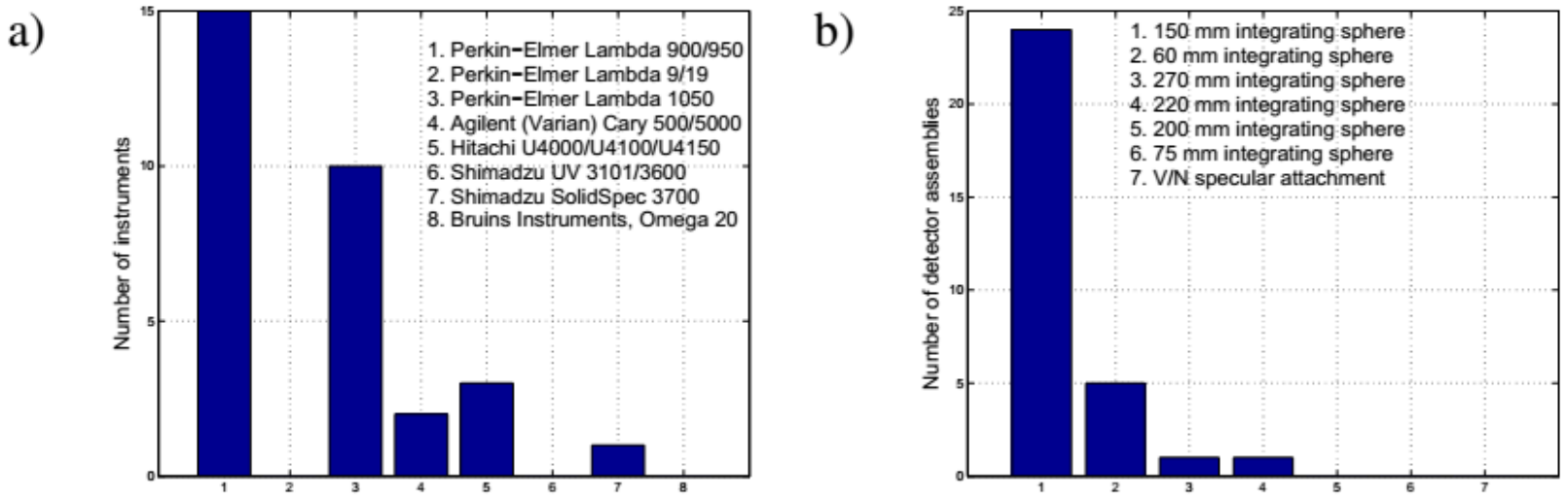


Figure 2: a) Distribution of instruments among the participants. b) Distribution of detector systems used.

- Instruments used by 36 participating laboratories, in a recent inter-laboratory comparison
  - The majority use Lambda 900/500 and 150 mm integrating sphere

Equipment

- Equipment preventive maintenance plan
  - Internal: cleaning and optics alignment, conducted quarterly
  - External: following PerkinElmer protocols, conducted annually

- Equipment calibration plan
  - Standard reference materials for 100%R auto-zeroing are calibrated annually by a national metrology laboratory
  - A set of backup standard reference materials are maintained, for internal verifications

Accommodation environment

- General indoor laboratory environment is sufficient for Lambda 950

- Temperature requirements:
  - Less than 32 °C when the instrument is not in use
  - Less than 25 °C (estimated) when the instrument is in use; otherwise, PbS detector is too noisy

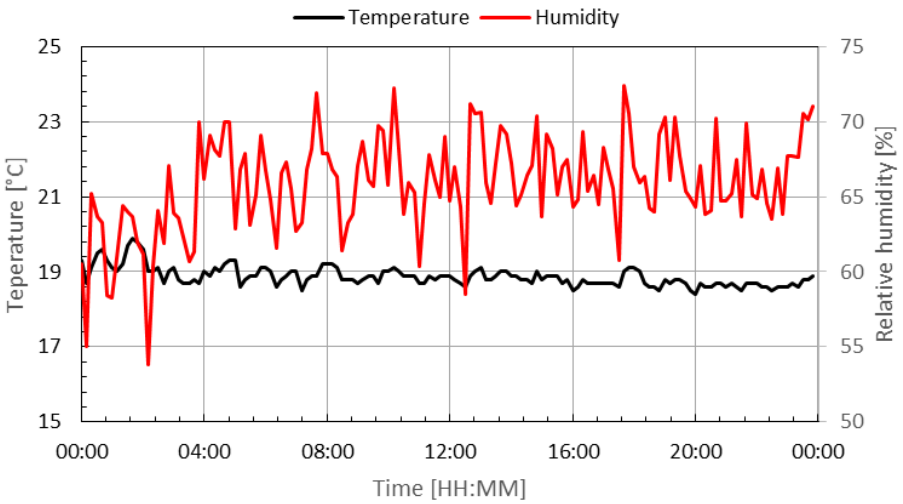
- Humidity requirements:
  - Less than 80% as specified in the manual
  - In practice, humidity is the major hazard to the instrument

  - Never use the instruments in non-air-conditioned environment
  - Don’t assume that humidity in air-conditioned environment is low, even if the air-con operates 7x24

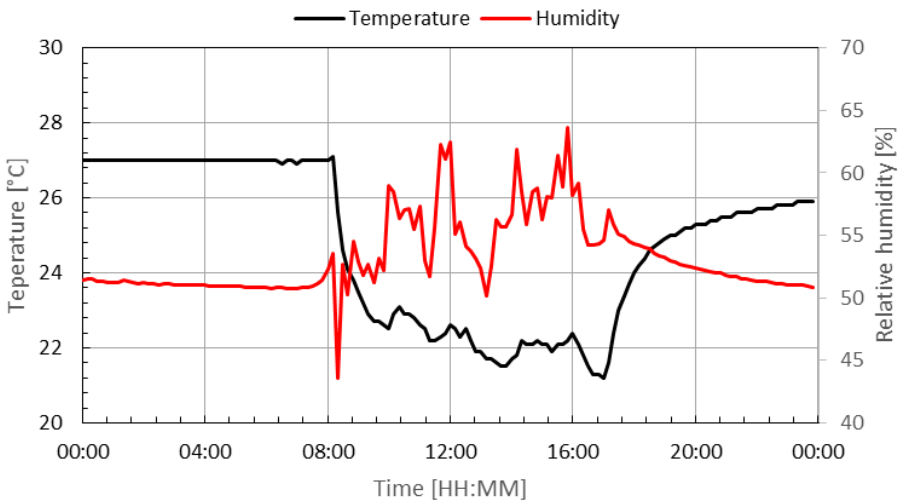
Accommodation environment

- Our practices
  - Reduce laboratory space air infiltration
  - Use dehumidifier to control humidity
  - Use air-con to control temperature
  - Monitor temperature & humidity with calibrated data logger
  - Cover the instrument when it is not in use

Accommodation environment



With air-con only



With air-con & dehumidifier

- Temperature is too low
- Relative humidity is high
- More energy consumption

VS

- Temperature is comfortable
- Relative humidity is lower
- Less energy consumption

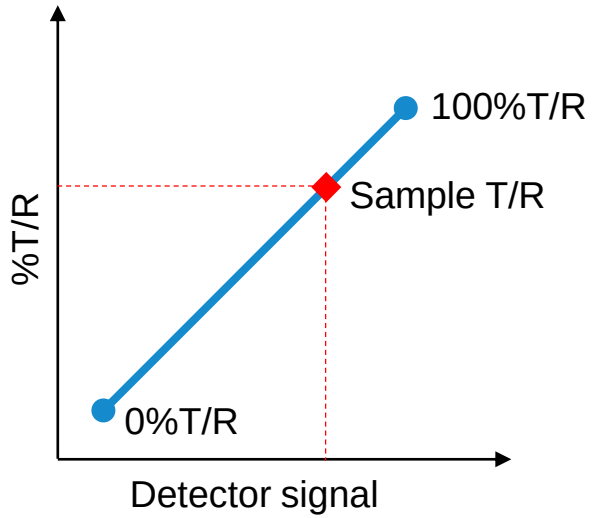
Staff competence

- Instruments are well engineered and software is user friendly
- For in-house laboratories, a staff with diploma or degree in engineering or equivalent should be qualified
- However, for laboratories providing third-party services, there are more challenges
  - ➢ Higher staff competence requirements for third-party testing laboratory

Test sample related	Test method related
• Very large samples • Very small samples • Non-flat samples • Non-uniform samples	• Work with multiple standards • Requirements for absolute accuracy and traceability • Complex calculation models

Measurement uncertainty

- Review of measurement principle
  1. 100%T/R baseline
  2. 0%T/R base line
  3. Sample measurement
  4. Scan through all wavelengths



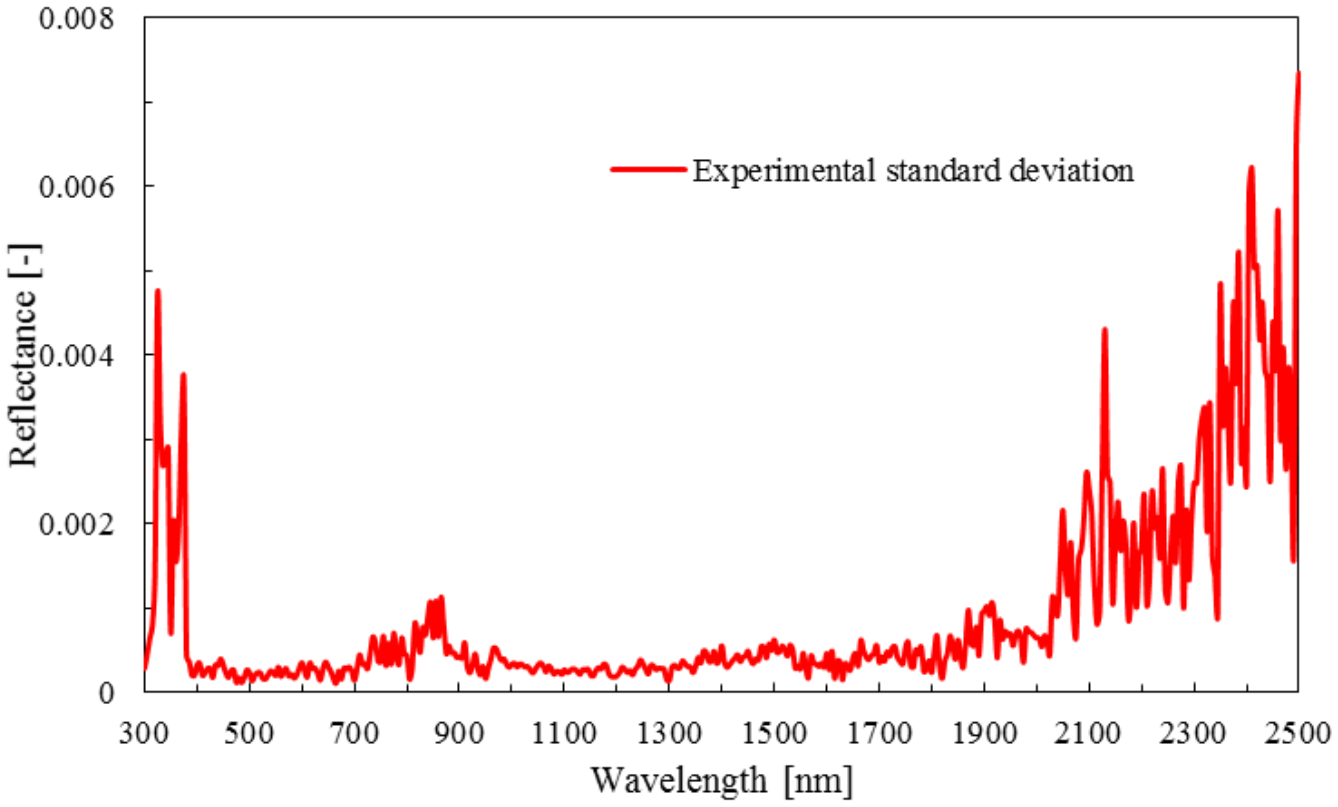
- Measurement uncertainty sources
  - ➢ 100%T/R baseline error
  - ➢ 0%T/R baseline error
  - ➢ Detector nonlinearity
  - ➢ Detector noise
  - ➢ Wavelength mismatch

Measurement uncertainty

- For transmittance measurement, 0%T and 100%T uncertainties can be ignored
  - Ideal 0%T and 100%T can be produced easily in the lab
- For reflectance measurement, 0%R and 100%R uncertainty cannot be ignored
  - Ideal 0%R and 100%R cannot be produced in the lab
  - Reflectance measurement is always less accurate than transmittance measurement
- 100%R uncertainty is the largest uncertainty source:
  - Uncertainty by the calibration laboratory
  - Maintenance by the testing laboratory, e.g. material degradation & contamination
- Due to the linear relationship, high reflectance results are less accurate than low reflectance results

Measurement uncertainty

- Uncertainty caused by detector noise needs to analysed for each instrument
  - PbS detector is noisy in 2000 nm – 2500 nm range
  - Solar energy is weak in this range, the larger noise causes little effect to broadband quantities



Measurement uncertainty

- Uncertainty caused by detector nonlinearity is small and negligible

- Uncertainty caused by wavelength mismatch is small and negligible to the calculated broadband quantities
  - However, it is still critical to check wavelength accuracy
  - It is not a significant uncertainty source, but is a highly possible error source

Measurement uncertainty

- Typical glass measurement uncertainties
  - ±0.003 for solar energy or visible light transmittance
  - ±0.006 for solar energy or visible light reflectance

- Typical general material measurement uncertainties
  - For low reflectance materials: ±0.004 for solar energy or visible light reflectance
  - For high reflectance materials: ±0.011 for solar energy or visible light reflectance

- Both are based on very conservative estimations

Quality assurance

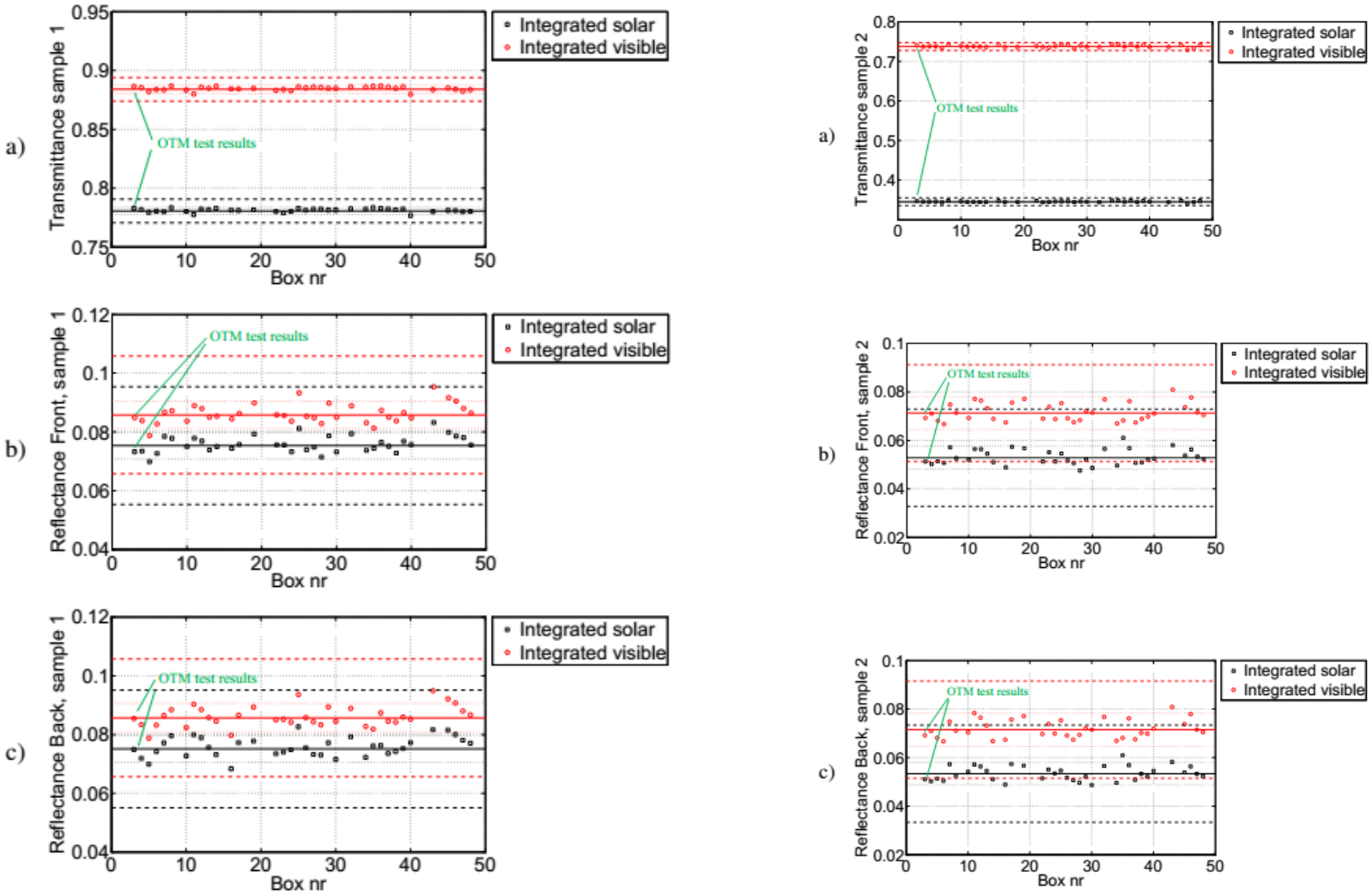
- The laboratory performs two types of quality assurance programs regularly
  - Internal re-test and comparison
  - Inter-laboratory comparison

Quality assurance

	Results in OTM1612005 For test sample 1612013	Quality assurance test results For test sample 1612013
Solar energy transmittance	0.106	0.107
Solar energy reflectance, front	0.163	0.164
Solar energy reflectance, back	0.462	0.464
Visible light transmittance	0.221	0.221
Visible light reflectance, front	0.095	0.096
Visible light reflectance, back	0.043	0.043
Emittance, front	0.844	0.844
Emittance, back	0.036	0.037

- Results of our recent quality assurance test conducted in 02/2017

Quality assurance



- Inter-laboratory comparison with 36 participating laboratories

ISO 17025

Organization	Control of threat	Control of document	Review of test request	Procurement
Feedback & complaints	Corrective & preventive actions	Control of record	Internal audit	**Staff competence**
Accommodation environment	**Estimation of uncertainty**	Control of data	**Equipment**	Measurement Traceability
Test sample handling	**Quality assurance**	Reporting test results	And more ……	

- ISO 17025 is a comprehensive laboratory quality management system

Thank you for your attention!

More information

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