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Visual and Non-visual Impacts of Commercial Self-luminous Signboards in Residential Areas in China

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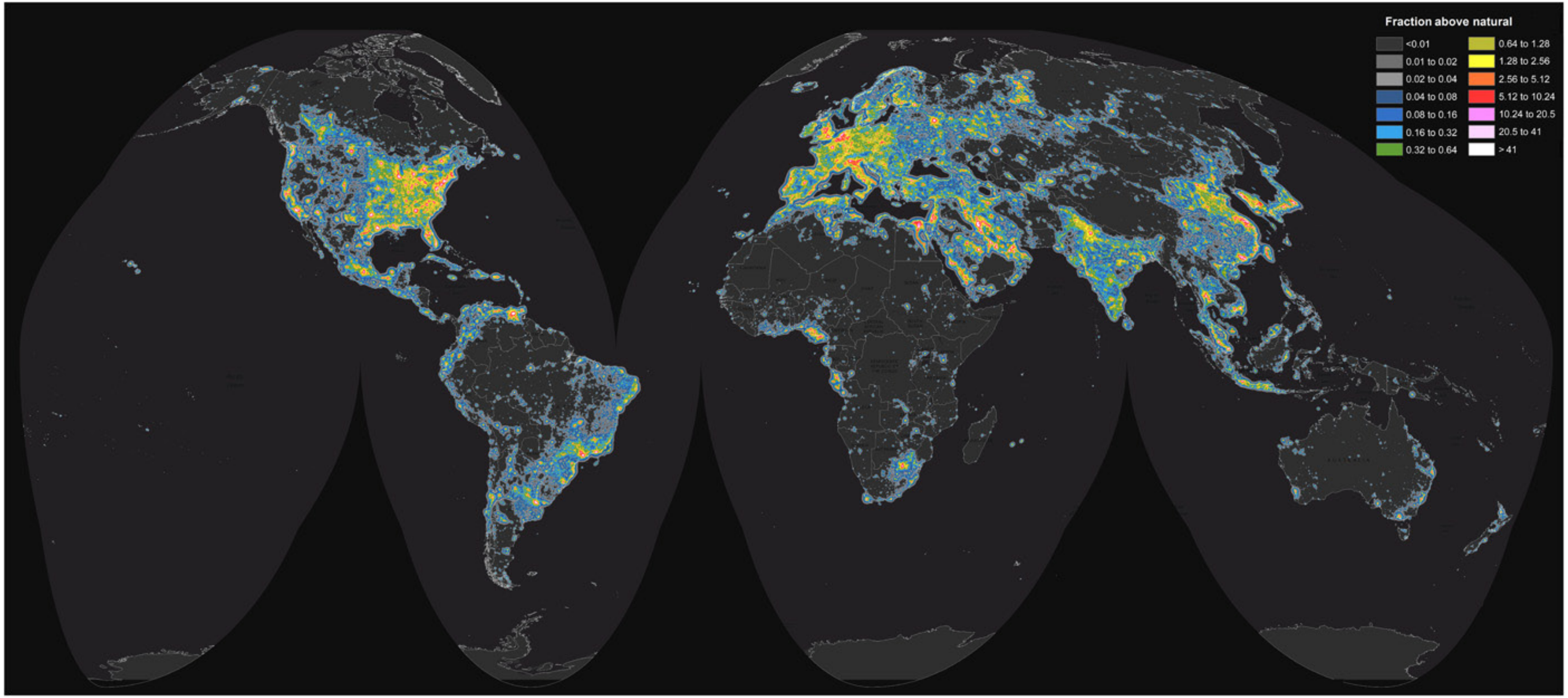
Light Pollution in China

Light pollution is the fifth largest pollution after air pollution, water pollution, solid waste pollution and noise pollution, which includes light trespass, over-illumination, glare, light clutter and skyglow. Light pollution can affect both ecological environments and human health, and has become a worldwide problem.

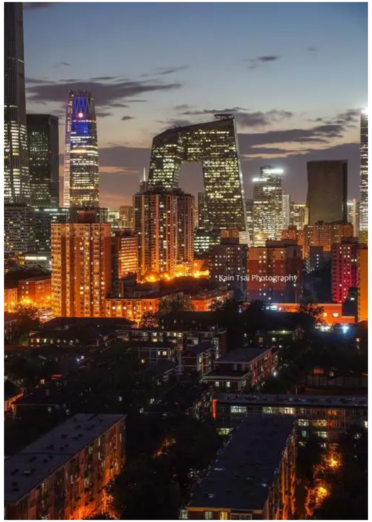


@ Falchi et al., 2016

Light Pollution in China

Although the Urban Lighting Projects (ULP) has played an important role in shaping cities' nighttime landscape, excessively bright lighting environments at night interfere with the advancement of astronomical research, affect the growth of animals and plants, reduces the quality of residents' sleep as well as increase their risk of having cancer.
Characteristics of light pollution: physical pollution, locality, no residue and relativity.

Shang Hai



Bei Jing

Shen Zhen

Mixed Commercial-Residential Buildings

Nan Jing

Wu Han

Zheng Zhou

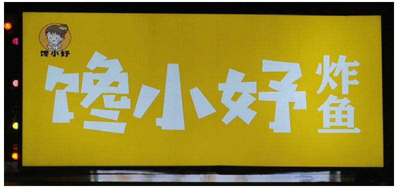
Qing Dao

• Mixed commercial and residential buildings (stores on the first floor and residence on the upper floors) are widely used in China. The close relationships between business and residents provides residents with convenience and light pollution in their daily life;

• The signboards of Nanjing shops have the characteristics of different colors (spectral compositions), relatively standardized designs (store names), and large luminance ranges (photopic & circadian aspects).

Four Signboard Types

T1: Neon-based profile



T3: Internal lightbox

T1: Neon-based billboard

T3: External floodlight

T2: LED-based profile

T4: Mixed lighting systems

T2: LED-based billboard

T4: Mixed lighting systems

(Tong, Z., 2017)

Projection signboard

Surface signboard

State of the Art

• Ngarambe et al. found that 30% of commercial boards and 70% of decoration lights in Seoul had light pollution (Ngarambe et al., 2018).

• Cha et al. systematically sorted out the “Light Pollution Prevention and Control Law”, measured the vertical illuminance of 90 windows, and found that 26% of the measured data exceeded the design criteria, 45% of the average luminance values of building facades exceeded the design criteria, and 36% of the signboards exceeded the design criteria (Cha et al., 2014).

• Chen et al. found that 47% of measured signboard in Shanghai and 86% of measured signboard in Hongkong presented great circadian stimulus over 0.05 (Chen, 2019).

• Ho and Lin evaluated shop signboards in Taiwan using measurement and simulation, and found that oversized signboards, high densities, and inappropriate installation were the main reason for signboard light pollution (The errors between simulation and measurement are 16.1% and 16.6% along two sides without considering light spectral compositions.) (Ho and Lin, 2015).

• Guanglei et al. compared the light pollution control standards in South Korea between those in China and pointed out the simplicity and generalization of these standards. Light pollution policies in China lack standards for decorative lighting and advertising lighting; while South Korea’s light pollution policies aim to control the level of luminance emitted by a single signboard rather than the net luminance emitted by all signs on a building’s facade (Guanglei, 2019).

To sum up, the light pollution problem of shop signboards is an Asian wide problem. There are limited studies concerning visual and non-visual impacts of signboards. Moreover, studies that use simulation methods could be further explored.

Associated Codes and Regulations

Code name	Zone	Maximum permitted average values of self-luminous signboards (cd/m²)			
		(0, 0.5] m^2	(0.5, 2] m^2	(2, 10] m^2	(10, ∞) m^2
Code for lighting design of urban nightscape (JGJ/T163-2021) Tianjin technical standard for urban nightscape lighting (DB/T29-71-2021)	E3	800	600	450	300
Guangzhou code for outdoor billboard and signboard designs Wuhan code for outdoor billboard and signboard designs	Residential areas	100	80	60	40
Shenzhen technical standard of urban landscape lighting engineering (SJG 105-2021)	E3	800			
Shanghai code for urban lighting environment (decoration)	E3	500			

- CIE, IESNA-DSA and BSI all restrict 800 cd/m^2 as the maximum allowable value for E3;
- Different provinces and cities in China have different regulations of signboard luminance thresholds as well as the factors upon which these regulations are established on, such as self-luminous areas and installation height;
- The maximum allowable illuminance on the surface of exterior windows is not convenient for designers to quickly apply in practical projects;

	Installation position	Maximum permitted average luminance (cd/m²)	Installation position	Maximum permitted average luminance (cd/m²)
Chongqing technical standards for outdoor billboards Qingdao technical standards for outdoor billboards Tianjin technical standards for outdoor billboards	Billboard and signboards on shopping malls	250-500	Commercial billboards and gas station light boxes	700-1000
	Low luminous locations with dark billboard background	450-700	High-rise buildings and downtown areas	1000-1400

	Billboards and signboards	Self-luminous area <2 m² (lx)	Self-luminous area >8 m² (lx)
Qingdao technical standards for outdoor billboards Jiangsu technical standards for outdoor billboards	Billboards and signboards along roads and sidewalks (below 10m)	200～400	200～600
	Billboards and signboards along roads and sidewalks (height 10m ~ 40m)	——	300～1000
	Billboards and signboards along roads and sidewalks (height 40m ~ 50m)	——	400～1200

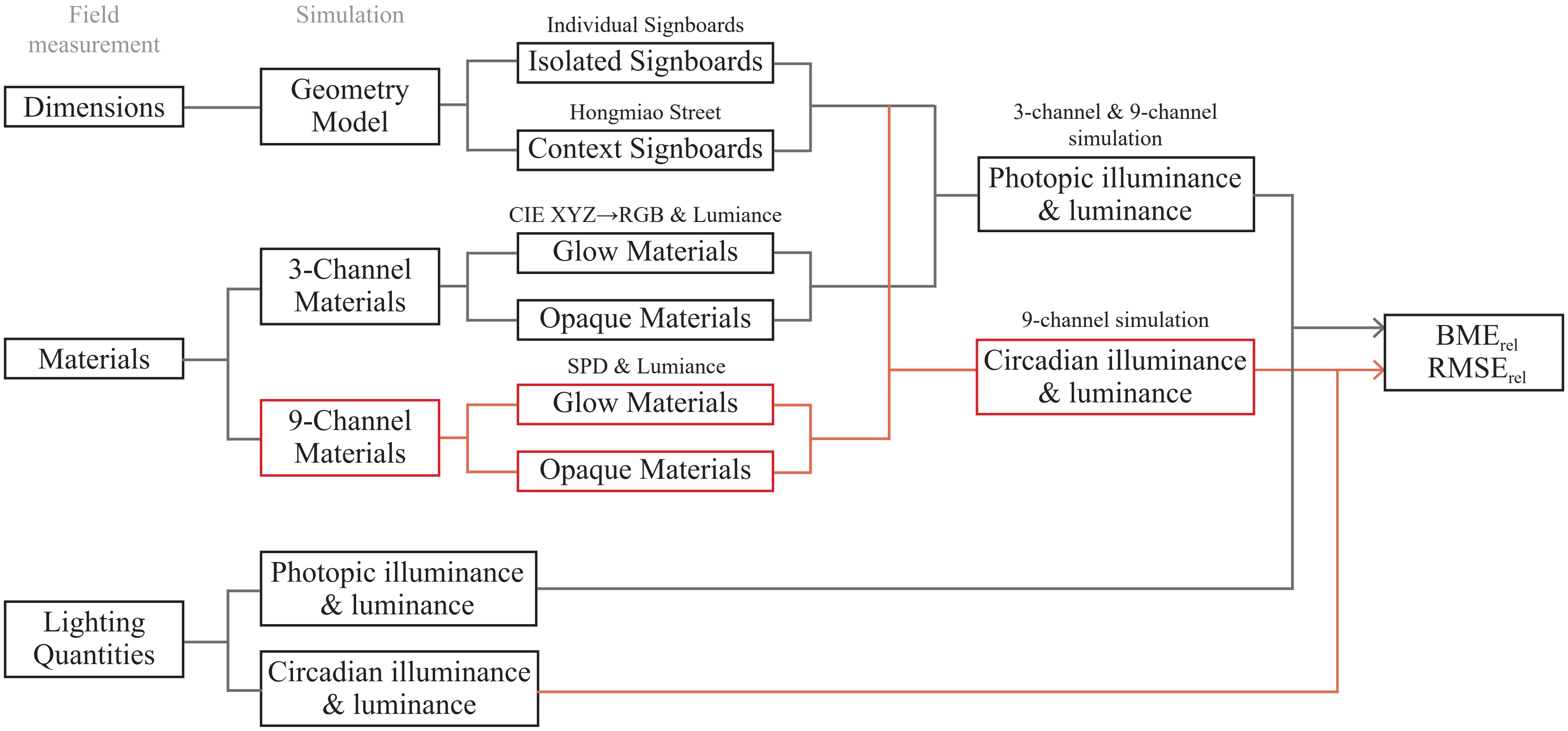
- Currently, Chinese codes and standards associated with signboards lack circadian illuminance/luminance thresholds from the colour and spectral perspectives.

Research objectives

- **Propose and verify a method that integrates measurement and simulation for self-luminous lightbox signboards;**

- **Evaluate the lighting quality within mixed residential areas in Nanjing at night from both visual and non-visual aspects.**

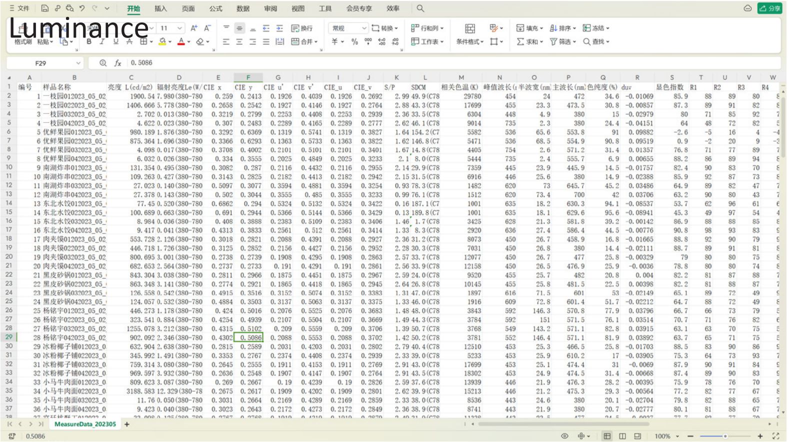
Research Flow

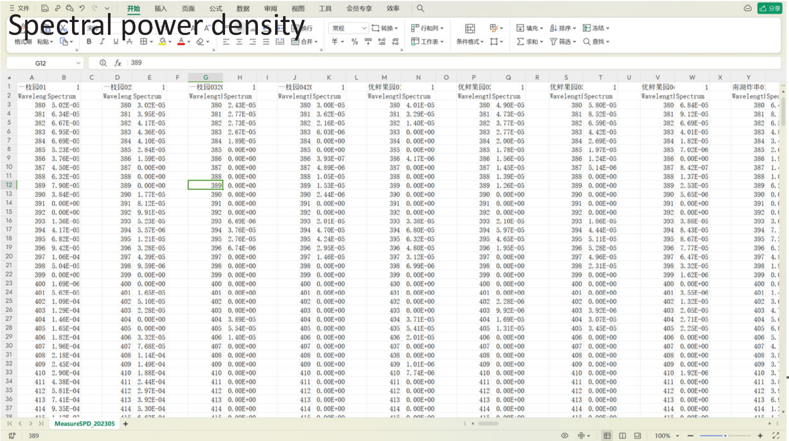


Method - Field Measurement

Luminance & SPD measure

Measured points

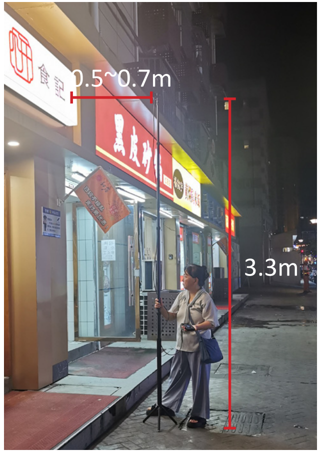




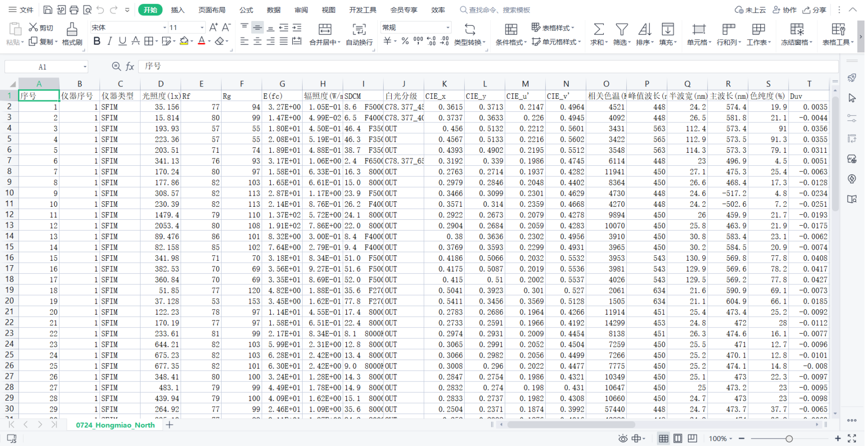
Use a portable spectroradiometer (SRC-2) to measure both luminance and spectral composition of each signboard one hour after sunset. Two to five points were measured for each signboard.

Method - Field Measurement

Illuminance & SPD measure



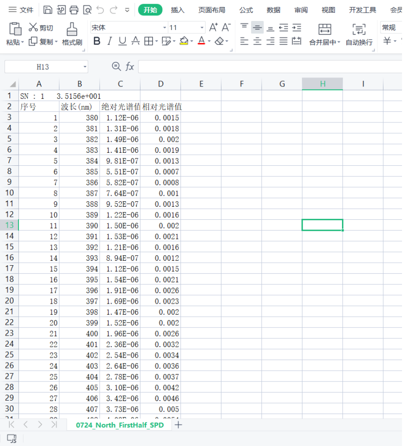
Illuminance



序号	仪器序号	仪器类型	光照度(lx)	Rf	Rg	E(fc)	辐照度(W/n	SDCM	白光分级	CIE_x	CIE_y	CIE_u'	CIE_v'	相关色温(K	峰值波长(r	半波宽(nm)	主波长(nm)	色纯度(%)	Duv
1	1	SFIM	35.156	77	94	3.27E+00	1.05E-01	8.6 F500(	C78.377_45	0.3615	0.3713	0.2147	0.4964	4521	448	24.2	574.4	19.9	0.0035
2	1	SFIM	15.814	80	99	1.47E+00	4.99E-02	6.5 F400(	C78.377_40	0.3737	0.3633	0.226	0.4945	4092	448	26.5	581.8	21.1	-0.0044
3	1	SFIM	193.93	57	55	1.80E+01	4.50E-01	46.4 F35(	OUT	0.456	0.5132	0.2212	0.5601	3431	563	112.4	573.4	91	0.0356
4	1	SFIM	223.36	57	55	2.08E+01	5.19E-01	46.3 F35(	OUT	0.4567	0.5133	0.2216	0.5602	3422	565	112.9	573.5	91.3	0.0355
5	1	SFIM	203.51	71	74	1.89E+01	4.88E-01	38.7 F35(	OUT	0.4393	0.4902	0.2195	0.5512	3548	563	114.3	573.3	79.1	0.0311
6	1	SFIM	341.13	76	93	3.17E+01	1.06E+00	2.4 F650(	C78.377_65	0.3192	0.339	0.1986	0.4745	6114	448	23	496.9	4.5	0.0051
7	1	SFIM	170.24	80	97	1.58E+01	6.33E-01	16.3 800(	OUT	0.2763	0.2714	0.1937	0.4282	11941	450	27.1	475.3	25.4	-0.0063
8	1	SFIM	177.86	82	103	1.65E+01	6.61E-01	15.0 800(	OUT	0.2979	0.2846	0.2048	0.4402	8364	450	26.6	468.4	17.3	-0.0128
9	1	SFIM	308.57	82	113	2.87E+01	1.17E+00	23.9 F50(	OUT	0.3466	0.3099	0.2301	0.4629	4730	448	24.6	-517.2	4.8	-0.0234
10	1	SFIM	230.39	82	113	2.14E+01	8.76E-01	26.2 F40(	OUT	0.3571	0.314	0.2359	0.4668	4270	448	24.2	-502.6	7.2	-0.0251
11	1	SFIM	1479.4	79	110	1.37E+02	5.72E+00	24.1 800(	OUT	0.2922	0.2673	0.2079	0.4278	9894	450	26	459.9	21.7	-0.0193
12	1	SFIM	2053.4	80	108	1.91E+02	7.86E+00	22.0 800(	OUT	0.2904	0.2684	0.2059	0.4283	10070	450	25.8	463.9	21.9	-0.0175
13	1	SFIM	89.476	86	101	8.32E+00	3.00E-01	8.4 F400(	OUT	0.38	0.3636	0.2302	0.4956	3910	450	30.8	583.4	23.1	-0.0062
14	1	SFIM	82.158	85	102	7.64E+00	2.79E-01	9.4 F400(	OUT	0.3769	0.3593	0.2299	0.4931	3965	450	30.2	584.5	20.9	-0.0074
15	1	SFIM	341.98	71	70	3.18E+01	8.34E-01	51.0 F50(	OUT	0.4186	0.5066	0.2032	0.5532	3953	543	130.9	569.8	77.8	0.0408
16	1	SFIM	382.53	70	69	3.56E+01	9.27E-01	51.6 F50(	OUT	0.4175	0.5087	0.2019	0.5536	3981	543	129.9	569.6	78.2	0.0417
17	1	SFIM	360.84	70	69	3.35E+01	8.69E-01	52.0 F50(	OUT	0.415	0.51	0.2002	0.5537	4026	543	129.5	569.2	77.8	0.0427
18	1	SFIM	51.85	77	120	4.82E+00	1.88E-01	35.6 F27(	OUT	0.5041	0.3923	0.301	0.527	2061	634	21.6	590.9	69.1	-0.0073
19	1	SFIM	37.128	53	153	3.45E+00	1.62E-01	77.8 F27(	OUT	0.5411	0.3456	0.3569	0.5128	1505	634	21.1	604.9	66.1	0.0185
20	1	SFIM	122.23	78	97	1.14E+01	4.55E-01	17.4 800(	OUT	0.2783	0.2686	0.1964	0.4266	11914	451	25.4	473.4	25.2	-0.0092
21	1	SFIM	170.19	77	97	1.58E+01	6.51E-01	22.4 800(	OUT	0.2733	0.2591	0.1966	0.4192	14299	453	24.8	472	28	-0.0112
22	1	SFIM	233.61	81	99	2.17E+01	8.34E-01	8.1 8000K	OUT	0.2974	0.2931	0.2009	0.4454	8138	451	26.3	474.6	16.1	-0.0077
23	1	SFIM	644.21	82	103	5.99E+01	2.31E+00	12.8 800(	OUT	0.3065	0.2991	0.2052	0.4504	7259	450	25.5	471	12.7	-0.0096
24	1	SFIM	675.23	82	103	6.28E+01	2.42E+00	13.4 800(	OUT	0.3066	0.2982	0.2056	0.4499	7266	450	25.2	470.1	12.8	-0.0101
25	1	SFIM	677.35	82	101	6.30E+01	2.42E+00	9.0 8000K	OUT	0.3008	0.296	0.2022	0.4477	7775	450	25.2	474.1	14.8	-0.008
26	1	SFIM	348.41	80	100	3.24E+01	1.28E+00	14.3 800(	OUT	0.2847	0.2754	0.1986	0.4321	10349	450	25.1	473	22.3	-0.0097
27	1	SFIM	483.1	79	99	4.49E+01	1.78E+00	14.9 800(	OUT	0.2832	0.274	0.198	0.431	10647	450	25	473.2	23	-0.0095
28	1	SFIM	439.94	79	100	4.09E+01	1.62E+00	15.1 800(	OUT	0.2833	0.2737	0.1982	0.4308	10660	450	24.7	473	23	-0.0098
29	1	SFIM	264.92	77	99	2.46E+01	1.09E+00	35.6 800(	OUT	0.2504	0.2371	0.1874	0.3992	57440	448	24.7	473.7	37.7	-0.0065

0724_Hongmiao_North

Spectral Power Density



SN : 1 3.5156e+001

序号	波长(nm)	绝对光谱值	相对光谱值
1	380	1.12E-06	0.0015
2	381	1.31E-06	0.0018
3	382	1.49E-06	0.002
4	383	1.41E-06	0.0019
5	384	9.81E-07	0.0013
6	385	5.51E-07	0.0007
7	386	5.82E-07	0.0008
8	387	7.64E-07	0.001
9	388	9.52E-07	0.0013
10	389	1.22E-06	0.0016
11	390	1.50E-06	0.002
12	391	1.53E-06	0.0021
13	392	1.21E-06	0.0016
14	393	8.94E-07	0.0012
15	394	1.12E-06	0.0015
16	395	1.54E-06	0.0021
17	396	1.91E-06	0.0026
18	397	1.69E-06	0.0023
19	398	1.47E-06	0.002
20	399	1.52E-06	0.002
21	400	1.96E-06	0.0026
22	401	2.36E-06	0.0032
23	402	2.54E-06	0.0034
24	403	2.64E-06	0.0036
25	404	2.78E-06	0.0037
26	405	3.10E-06	0.0042
27	406	3.42E-06	0.0046
28	407	3.73E-06	0.005

0724_North_FirstHalf_SPD

Method - Data Processing

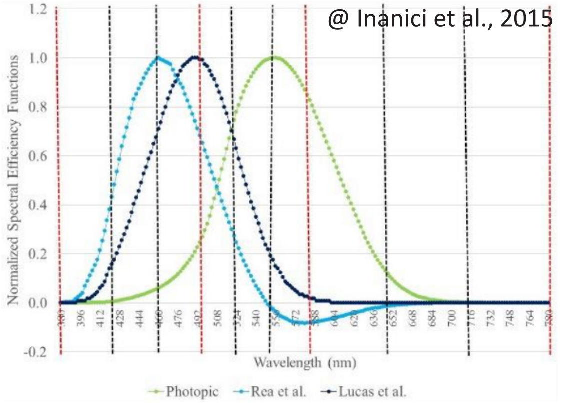
Models were built in Rhino and then exported to Grasshopper. The simulation results were verified from both visual and non-visual aspects. Concerning the visual aspect, Ladybug & Honeybee (Radiance) were used for simulation. In total, 75 isolated signboards were measured and simulated.

void glow modifier
0
0
4 R G B max_radius

Radiance RGB ⟶ CIE XYZ

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 2.5653 & -1.1668 & -0.3984 \\ -1.0221 & 1.9783 & 0.04382 \\ 0.0747 & -0.2519 & 1.1772 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

Method - Data Processing



void glow modifier_blue
0
0
4 b_1 b_2 b_3 *max_radius*

void glow modifier_green
0
0
4 g_1 g_2 g_3 *max_radius*

void glow modifier_red
0
0
4 r_1 r_2 r_3 *max_radius*

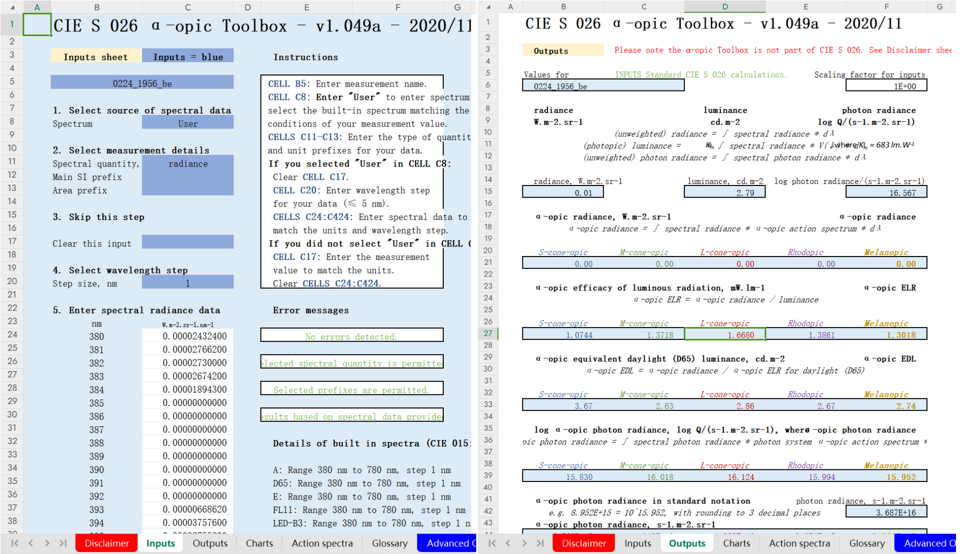
$$Sum = B_1 * p_{B1} + B_2 * p_{B2} + B_3 * p_B + G_1 * p_{G1} + G_2 * p_{G3} + G_3 * p_{G3} + R_1 * p_{R1} + R_2 * p_{R2} + R_3 * p_{R3}$$

$$b_n = \frac{B_n}{\mathrm{Sum}} * \frac{L_{mea}}{179}$$

	Wavelength	Photopic	Lucas et al.
B1	380-422	0.0004	0.0166
B2	422-460	0.0095	0.1819
B3	460-498	0.0522	0.3973
G1	498-524	0.1288	0.2468
G2	524-550	0.2231	0.1204
G3	550-586	0.3174	0.0351
R1	586-650	0.2521	0.0018
R2	650-714	0.0162	0
R3	714-780	0.0002	0

Lark (Inanici et al., 2015) uses a nine-channel simulation method, which requires both luminance and spectral data as the inputs. Lark calculates circadian illuminance and luminance following the response curve proposed by Lucas et al (2014).

Method - Data Processing



Measured circadian illuminance and luminance values were calculated by using the CIE alpha-opic Toolbox.

$$\mathrm{EML} = 72983.25 \int E_{e,\lambda}(\lambda)\ N_z(\lambda)\ d\lambda$$

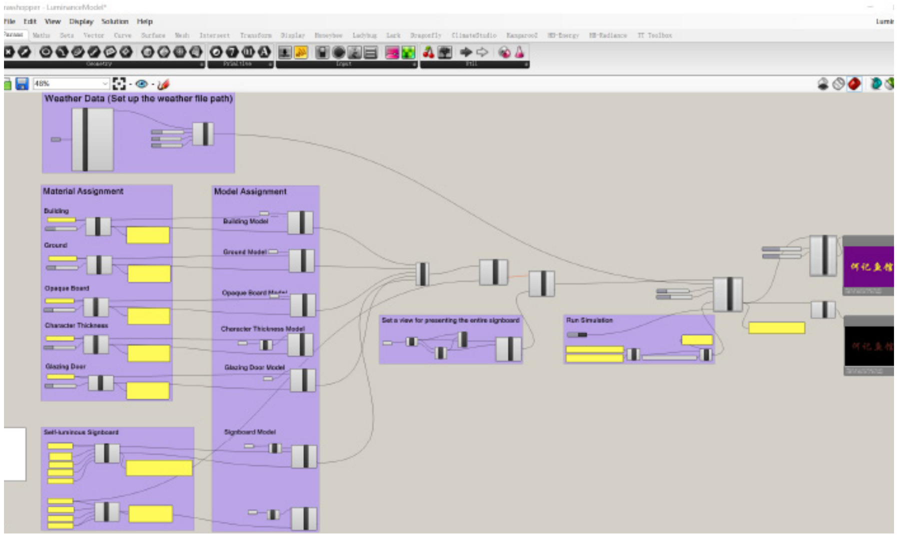
$$\text{melanopic EDI} = \frac{\int E_{e,\lambda}(\lambda) s_{mel}(\lambda) d\lambda}{K_{mel,V}^{D65}} = \frac{\int E_{e,\lambda}(\lambda) s_{mel}(\lambda) d\lambda}{1.3262\ mW \cdot lm^{-1}}$$

$$\frac{\text{melanopic EDI}}{\text{EML}} = 0.9063 \cdot \frac{\int E_{e,\lambda}(\lambda) s_{mel}(\lambda) d\lambda}{\int E_{e,\lambda}(\lambda)\ N_z'(\lambda)\ d\lambda}$$

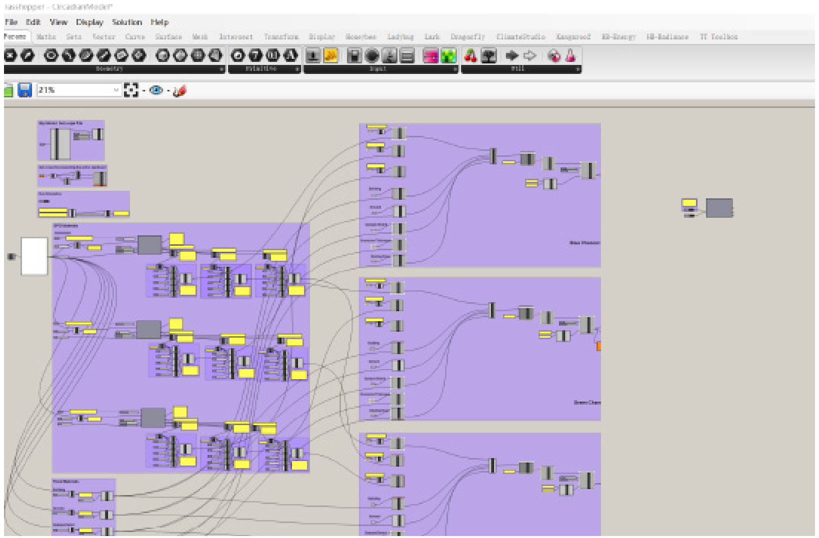
Measured EDI = 0.9063 x Simulated EML (Li. et al., 2022)

Method - Simulation

3-channel Radiance simulation



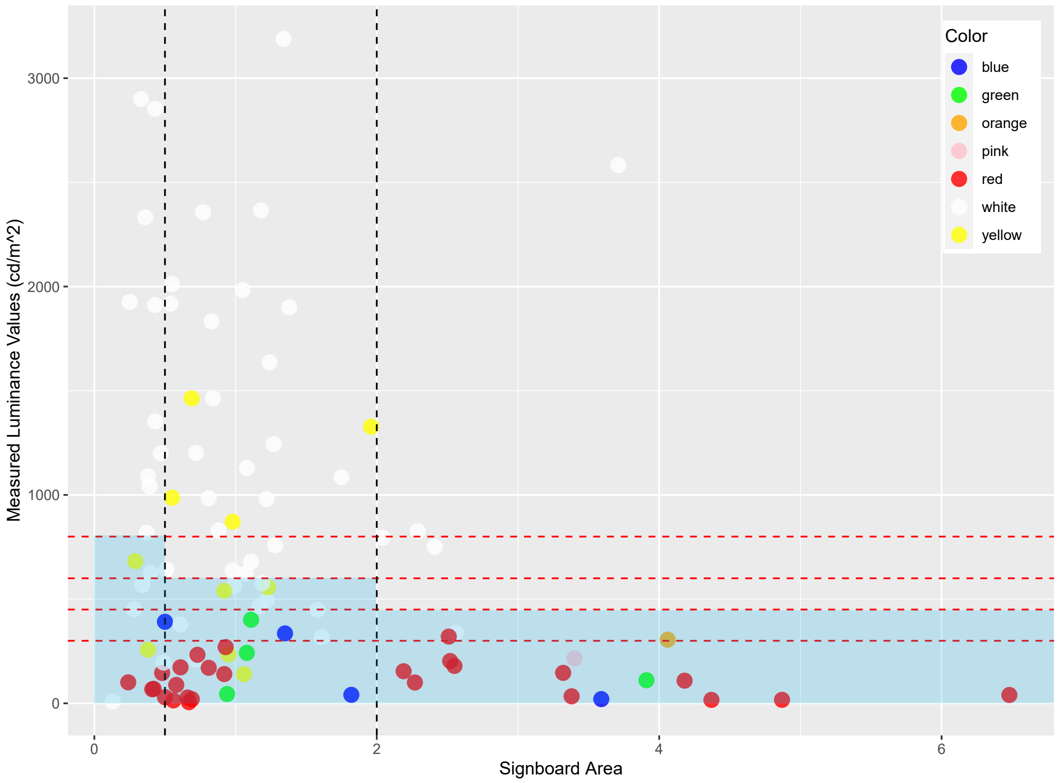
9-channel LARK simulation



$$MBE_{rel} = \frac{1}{N}\sum_{i=1}^{N} \frac{X_{sim,\, i} - X_{mea,\, i}}{X_{mea,\, i}}$$

$$RMSE_{rel} = \frac{1}{X_{avg-mea}}\sqrt{\frac{\sum_{i=1}^{N} \left(X_{sim,\, i} - X_{mea,\, i}\right)^2}{N}}$$

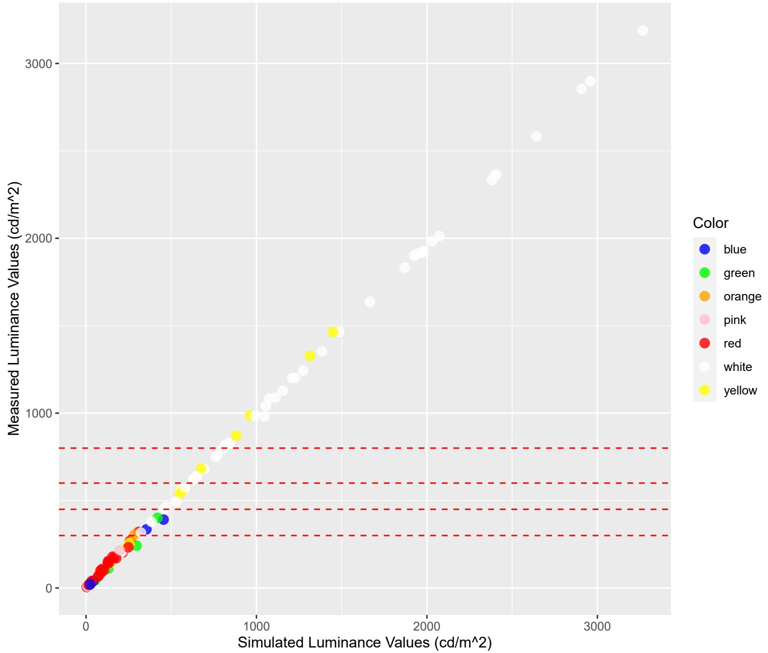
Results - Field Measurement

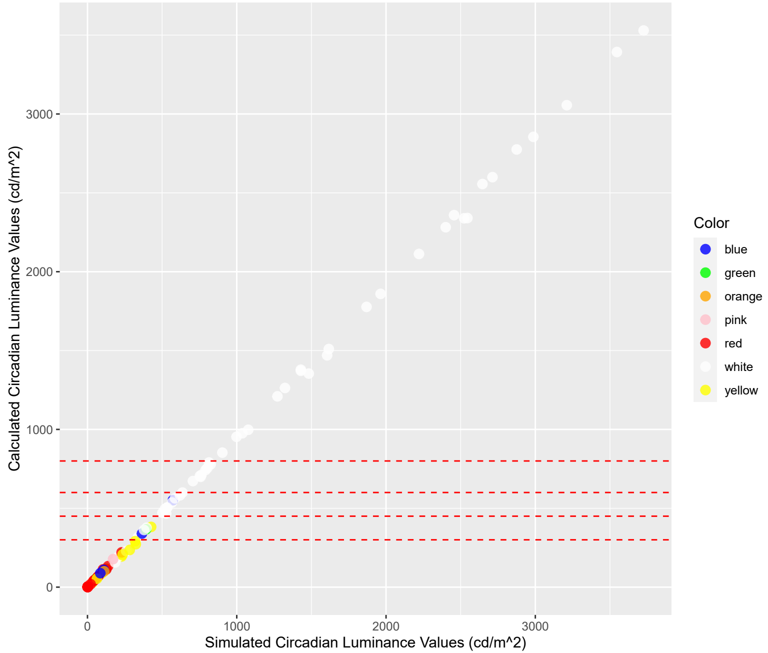


- White (50) and red (26) are the top and second most used colours for the signboards;
- White has the greatest values of mean luminance, luminance standard deviations, and luminance range;
- Red has the lowest values of mean luminance, luminance standard deviations, and luminance range;
- 42% of the measured data (most white ones and some yellow ones) exceeded the luminance thresholds required by the national code.

Color	Count	Mean lum. (cd/m^2)	Lum. Std. (cd/m^2)	Lum. range (cd/m^2)
Blue	4	196.9	193.7	20.3-391.3
Green	4	199.6	157.4	44.6-401.1
Yellow	10	706.0	454.7	139.9-1463.6
Red	26	110.4	86.0	5.4-320.3
White	50	1189.5	796.9	9.4-3188.6

Results - Simulations





	Photopic lum. MBE_{rel}	Photopic lum. $RMSE_{rel}$	Circadian lum. MBE_{rel}	Circadian lum. $RMSE_{rel}$
3-channel	0.66%	3.47%	--	--
9-channel	-0.74%	1.87%	-7.5%	7.8%

- Concerning photopic luminance, both 3-channel and 9-channel methods are able to simulate accurate results;
- Concerning circadian luminance, the Lark 9-channel method is also able to generate reliable results.

Results - Simulations

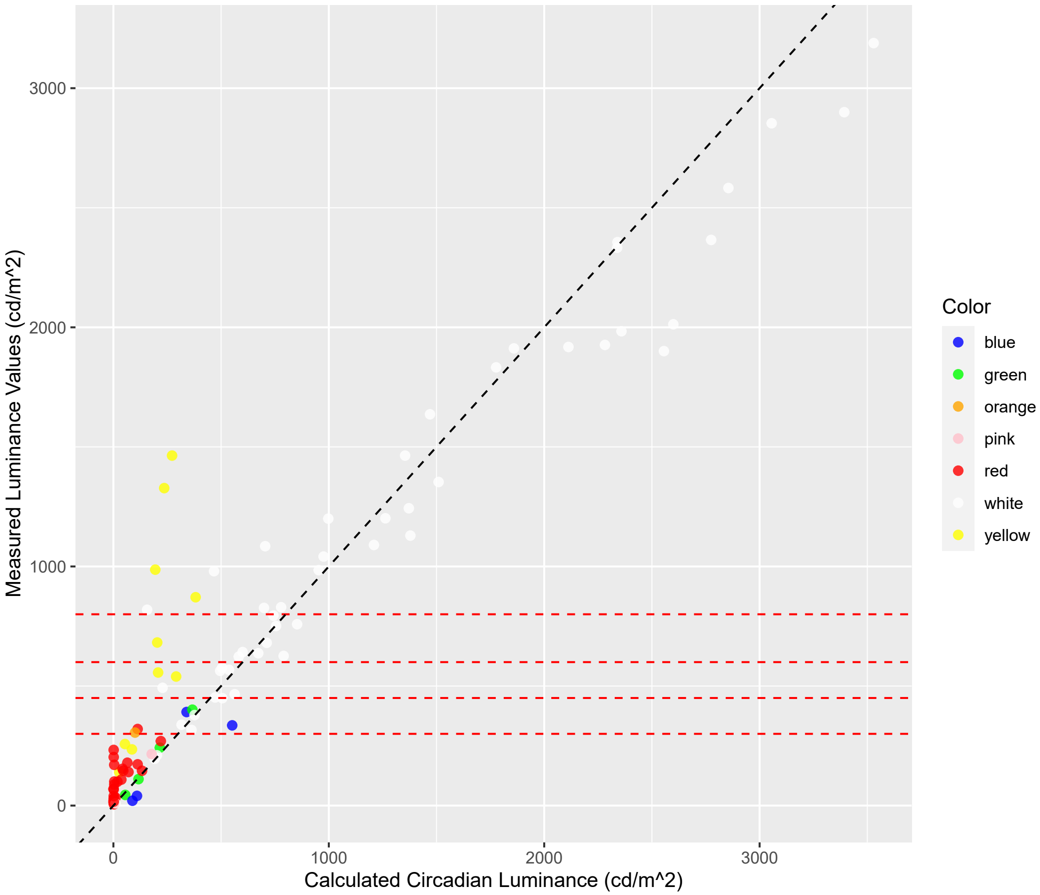
• White and blue signboards: circadian luminance values are much greater than photopic values;
• Red and yellow signboards: photopic luminance values are much greater than photopic luminance values;
• Green signboards: circadian luminance values and photopic luminance values are close, while the former is slightly lower than the latter.

Results - Simulations

• The white and blue signboards scatter around y=x, and the distances between white signboards and y=x depends on their CCT;

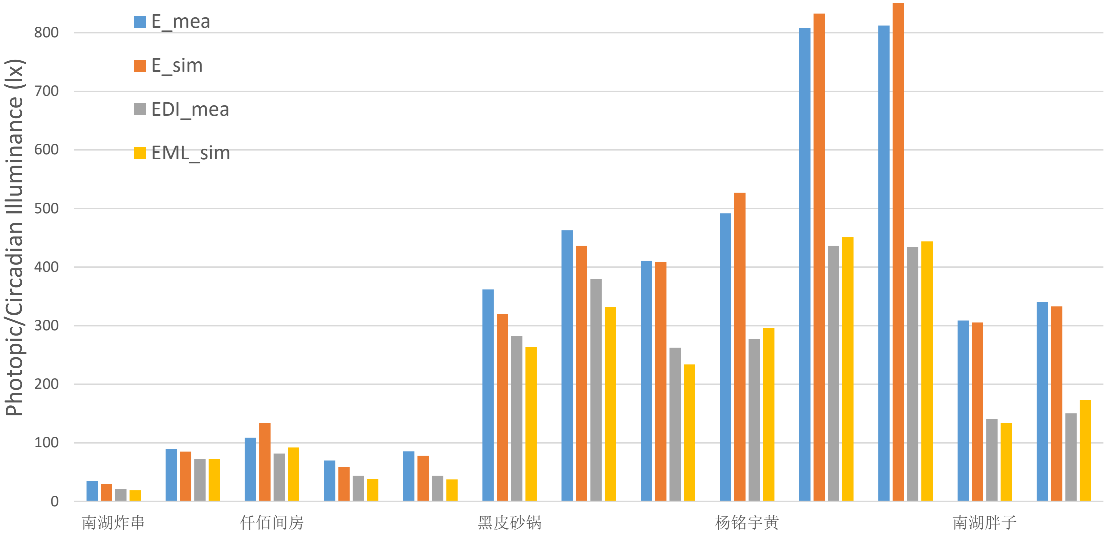
• Both red and yellow signboards are distributed in the upper part of y=x, and the distribution of green signboards is closest to y=x.

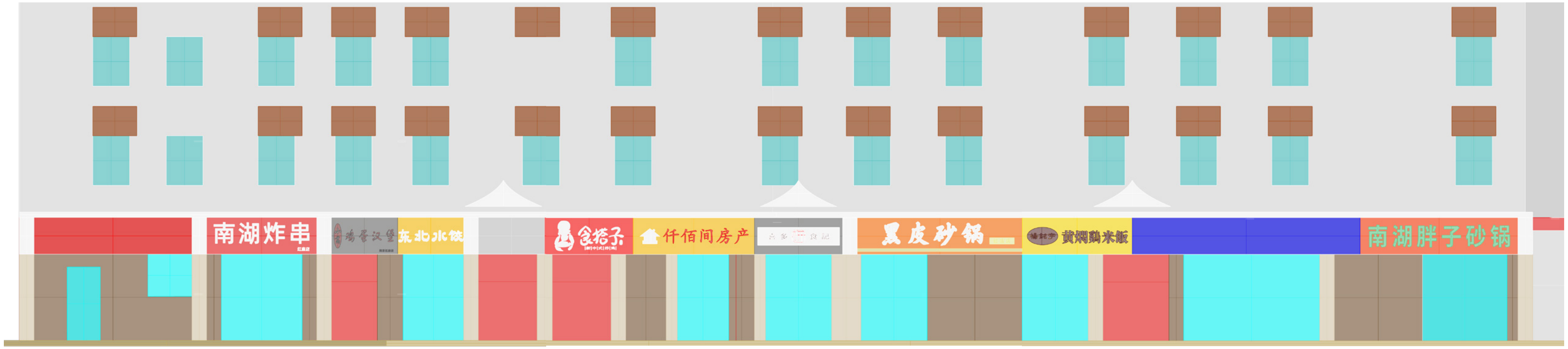
Colour	Count	Mean lum. (cd/m²)	Lum. Std. (cd/m²)	Lum. range (cd/m²)
Blue	4	196.9	193.7	20.3-391.3
		272.3	218.2	88.4-551.5
Green	4	199.6	157.4	44.6-401.1
		188.5	136.0	55.1-366.7
Yellow	26	110.4	86.0	5.4-320.3
		34.6	54.9	0.5-220.2
Red	10	706.0	454.7	139.9-1463.6
		195.4	111.6	27.0-381.8
White	50	1189.5	796.9	9.4-3188.6
		1231.9	941.0	9.4-3529.4



Results - Simulations

Further work is required throughout the entire Hongmiao street.





Conclusions & Ongoing Work

- Comparing to the measured data, both 3-channel and 9-channel methods are capable of simulating accurate photopic luminance values of colourful signboards;
- The 9-channel method is capable of simulating accurate circadian luminance values of colourful signboards;
- Commonly used colours of self-luminous signboards with the same photopic influence are recommended as below: red > yellow > green > warm white > cool white > blue;
- In the residential areas of Xuanwu District, Nanjing, nearly half (42%) of the measured "internal lightbox" signboards fail to meet the requirements of the "Code for Lighting Design of Urban Nightscape".

- Complete the context validation;
- Propose simplified algorithm of converting photopic luminance/illuminance to circadian luminance/illuminance for commonly used signboard colours;
- Propose design recommendations of commercial lightbox signboards backward, like selections of luminaire (characteristics and count), translucent materials (colours and transmittance), etc;
- Conduct the research in other cities to expand the context/environmental influences.

Thanks for listening.

Any comment or suggestion is appreciated!