1. Skimming Wind Analysis Map

Goal: to look for Grids with similar building heights >> High risk of experiencing skimming wind >> Low wind flow >> High Anthropogenic Heat in these subzones

When area is not very dense, need to study building height. When area is dense, does not need to consider building height, but need to identify areas of skimming wind flow.

In dense areas, building heights does little to affect wind flow, it is the variation in neighbouring building heights that affects risk of experiencing skimming wind

Cross check with: (to identify relationships)

- Average surface temperature/ UHI (to cross check with average surface temperature)
- Carbon emissions/ Energy Consumption (Increased emissions due to higher energy usage to reduce temperature)

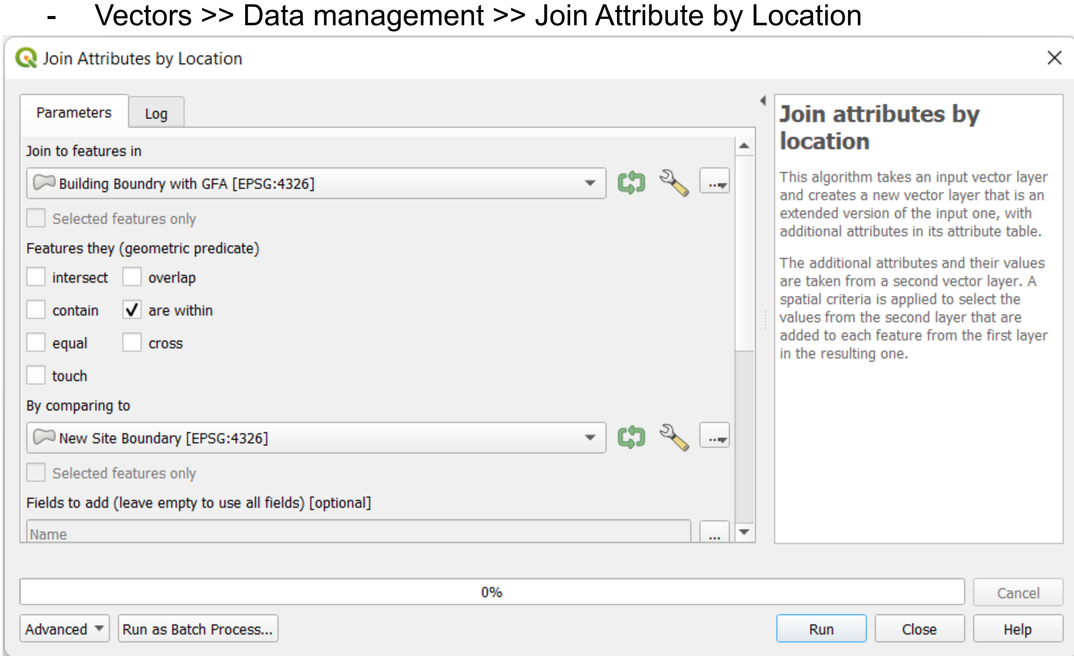
Method of Analysis:
In grids that fall under high density areas, do a stand dev of building heights. (high/ low variance of building heights in the area)
>> get: areas with high risk of skimming wind

1. Reduce data analysis area to "New Site Boundary"

Import Building footprint and height data (merged), clip to site boundary

2. Seperate Building Footprint based on subzones

- Import URA subzone map
- Vectors >> Data management >> Join Attribute by Location

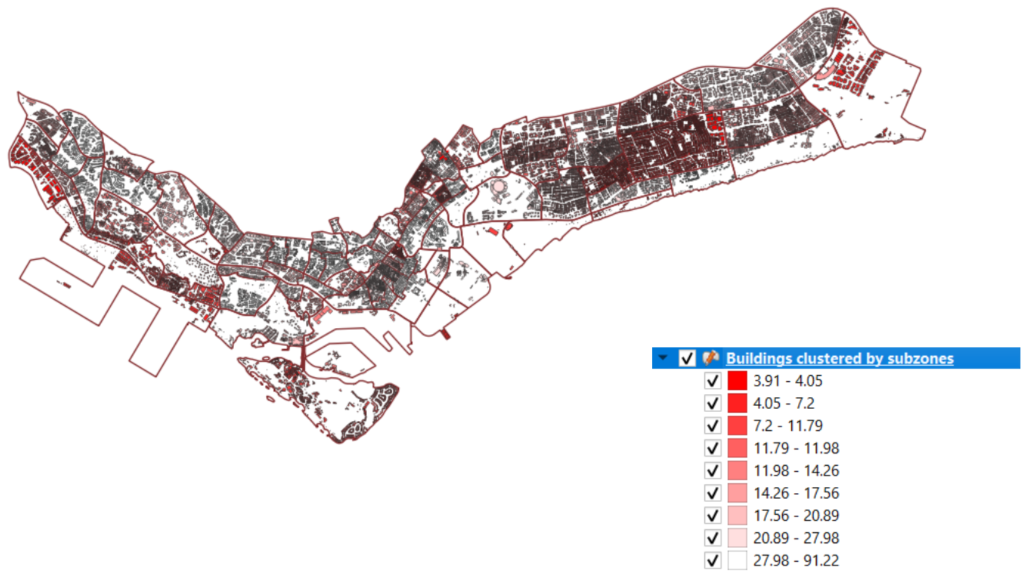


Join type: One to many

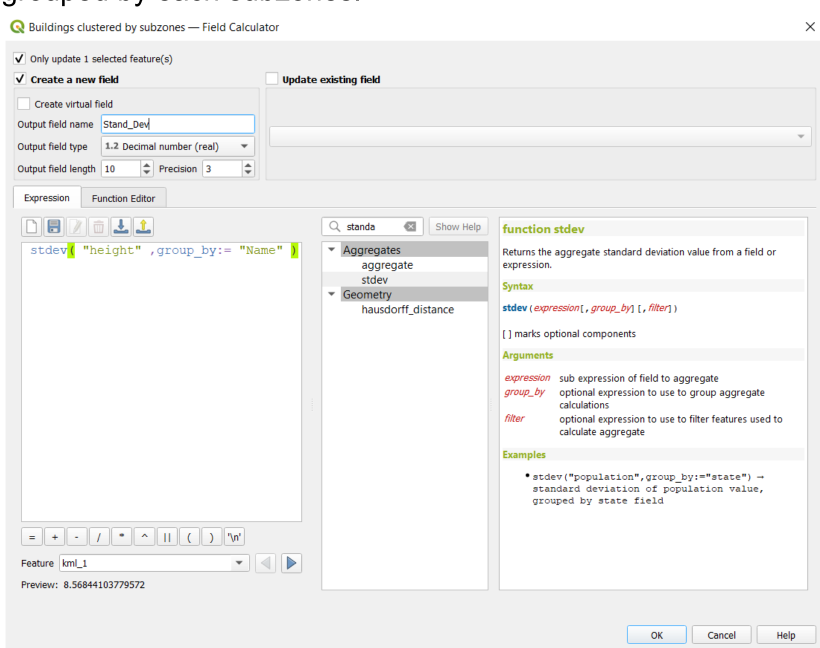
	fid	id	type	date	height	heightSrc	Floors	Building a	GFA	levels	Name
1	9437	osm-w503342113	commerce	201706	3.00000000000...	ai	1	347.398000000...	347.398000000...	NULL	kml_125

Result: “Subzone” Attribute added to “Building Footprint + Height”

3. Create attribute of “Standard Deviation” based on Building Height

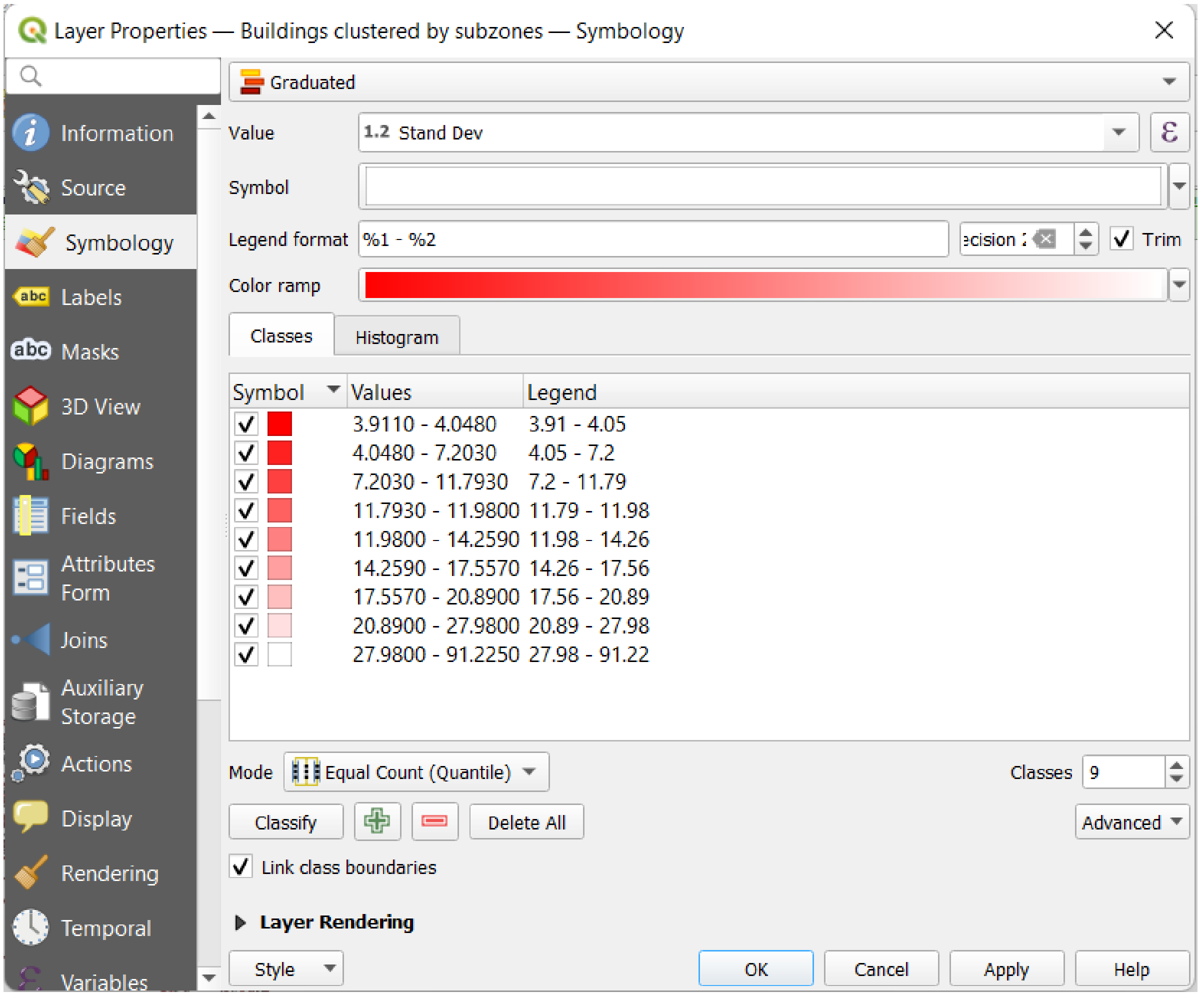


Attribute table >> Field Calculator >> create Standard deviation based on building heights, grouped by each subzones.



	fid	id	type	date	height	heightSrc	Floors	Building a	GFA	levels	Name	Stand Dev
1	9437	osm-w503342113	commerce	201706	3.00000000000...	ai	1	347.398000000...	347.398000000...	NULL	kml_125	3.911

Result: “Stand Dev” Attribute added to “Building Footprint + Height”

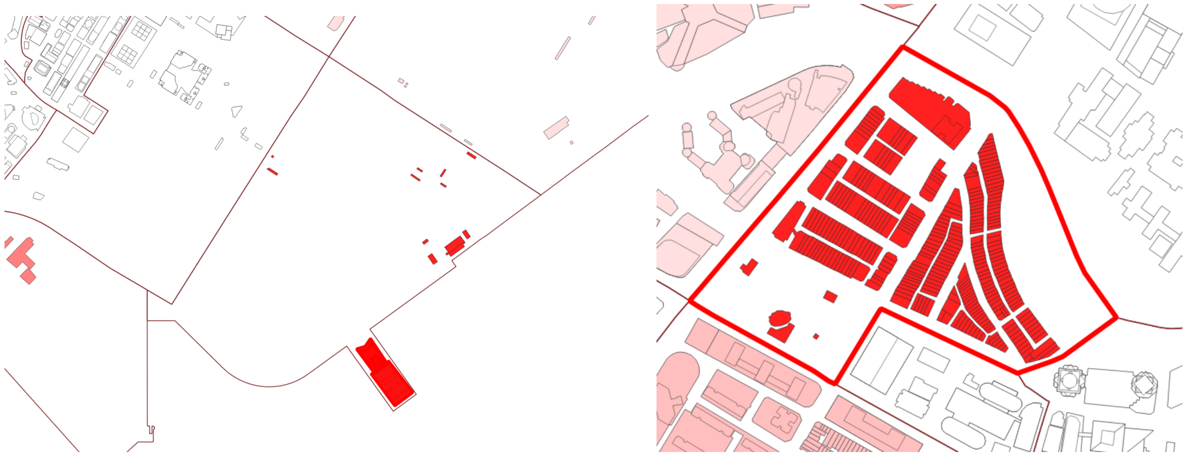


Presentation of data:

Properties >> Symbology >> Graduated classification of Data based on “Stand Dev” >> Equal Count

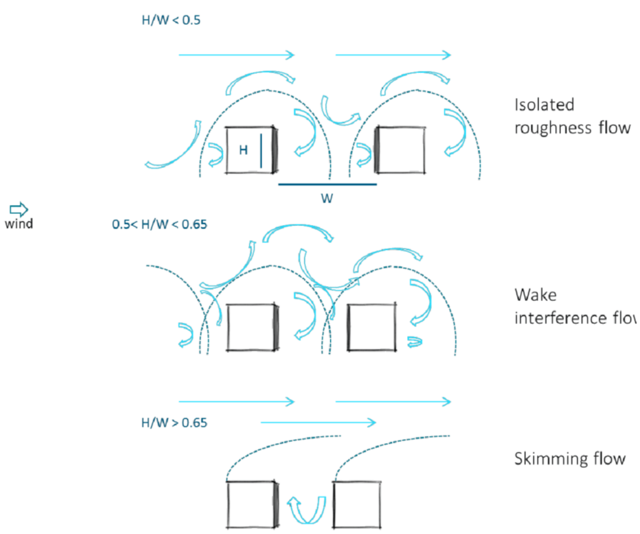
Results: the more red the subzone, the lower the standard deviation og building heights in the area. This means that there is a higher probability of skimming wind flow occurring. (Skimming wind flow happens when there is little to no variation in neighbouring building heights)

Assessment of accuracy:



Comparing results of KML_13 to KML_38

While results in KML_38 would most likely be accurate to determine the probability of skimming flow in the subzone, KML_13 would have low accuracy due to building density (used to approximate general building width) not being taken into account.



[1]

Conditions for Skimming wind

A primary qualitative analysis distinguishes the wind flow field with respect to the aspect ratio of the height (H) of the buildings to the width (w) of the space between them into three prevalent patterns. Skimming flow applies to very dense morphology with H/w aspect ratios greater than 0.65. The main air flow remains above the buildings' rooftops level and there is only one circulatory vortex formed inside the street canyon as a result of the momentum exchange.[2]

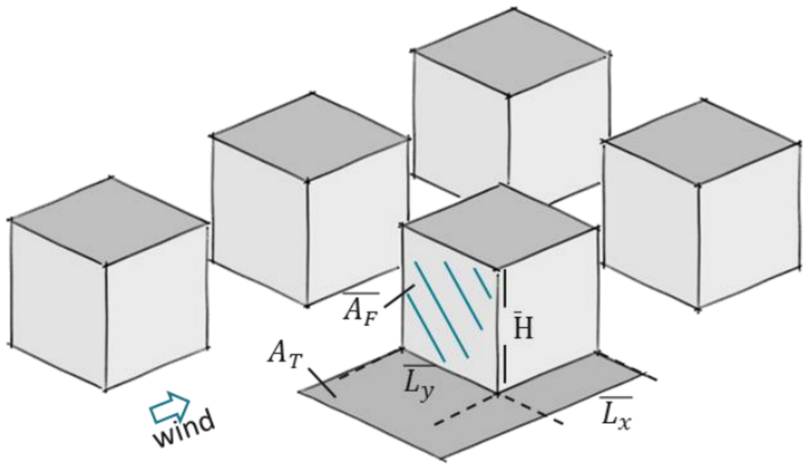
---

[1] Microclimate adapted localised weather data generation: implications for urban modelling and the energy consumption of buildings

[2] Microclimate adapted localised weather data generation: implications for urban modelling and the energy consumption of buildings

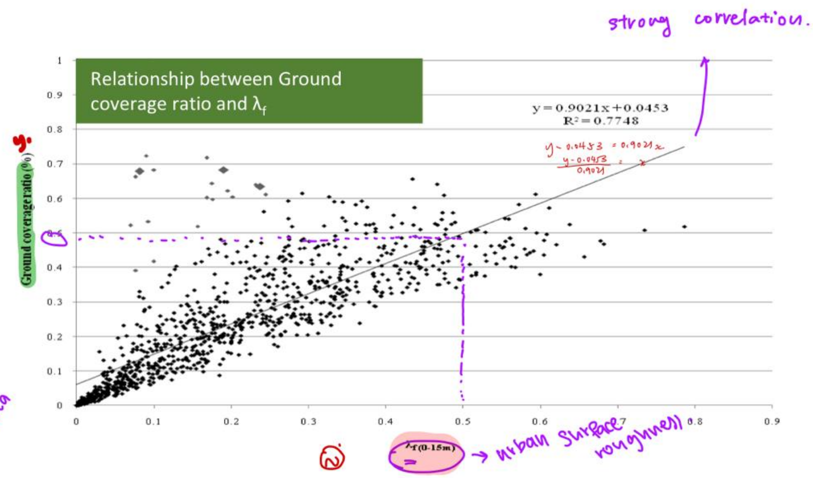
2. Urban Surface Roughness Map (Frontal Area Index λf)

The frontal area index λf is the ratio of the total building surface projection on a vertical plane perpendicular to the wind flow to the total area for each wind direction. It can be written as
$\lambda f = AF/AT$ (Frontal area divided by site area)



[3]

$$= \frac{A(\theta)_{proj(\Delta z)}}{A_T}$$



$GCR = \frac{A_b}{A_T}$ → built area. → site area

For normal urban areas.
(x big stadiums
x industries).

(For normal situations)
→ . just need GCR → to approximate λf.

There is also a relationship between Ground coverage ratio and λf.

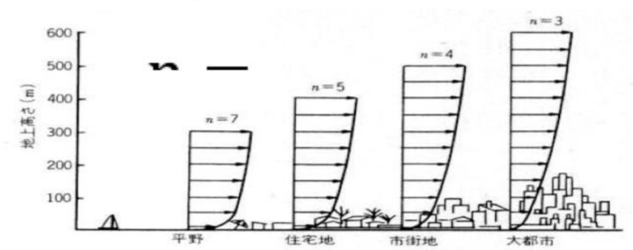
In order to predict the likely air flow corridors based on the premise that wind across a city follows the path of least resistance, least cost path (LCP) analysis was undertaken to designate

[3] Microclimate adapted localised weather data generation: implications for urban modelling and the energy consumption of buildings

these pathways across the city. LCP analysis identifies the path of least resistance across a cost surface from a starting point to an ending point. The pathways represent routes with a high probability of strong ventilation and a high degree of connectivity between starting and ending points. This study adopted the approach of allocating variable weightings to the frontal area index value of each pixel, e.g. the higher λf, the higher the friction value. The friction values represent the percentage of obstruction of wind ventilation or air flow for that 100 m pixel. By varying the lf classes and/or the friction weightings, it is possible to designate a few major pathways or many minor pathways. For example, this study adopted variable weightings in order to generate many different paths.[4] The λf pixel values were reclassified into five classes and each class was given a friction value according to the degree of wind obstruction, with higher friction values given to large frontal area values. This assumes that air is most obstructed in areas with high λf values, with lowest wind speed

地表面粗度区分		建設地および風上側地域の地表面の状況
滑	I	海面または湖面のような，ほとんど障害物のない地域
↑	II	田園地帯や草原のような農作物程度の障害物がある地域，樹木・低層建築物などが散在している地域
	III	樹木・低層建築物が多数存在する地域，あるいは中層建築物（4～9 階）が散在している地域
↓	IV	中層建築物（4～9 階）が主となる地域
粗	V	高層建築物（10 階以上）が密集する市街地

	I	II	III	IV	V (HK)
α	0.1	0.15	0.2	0.27	0.35

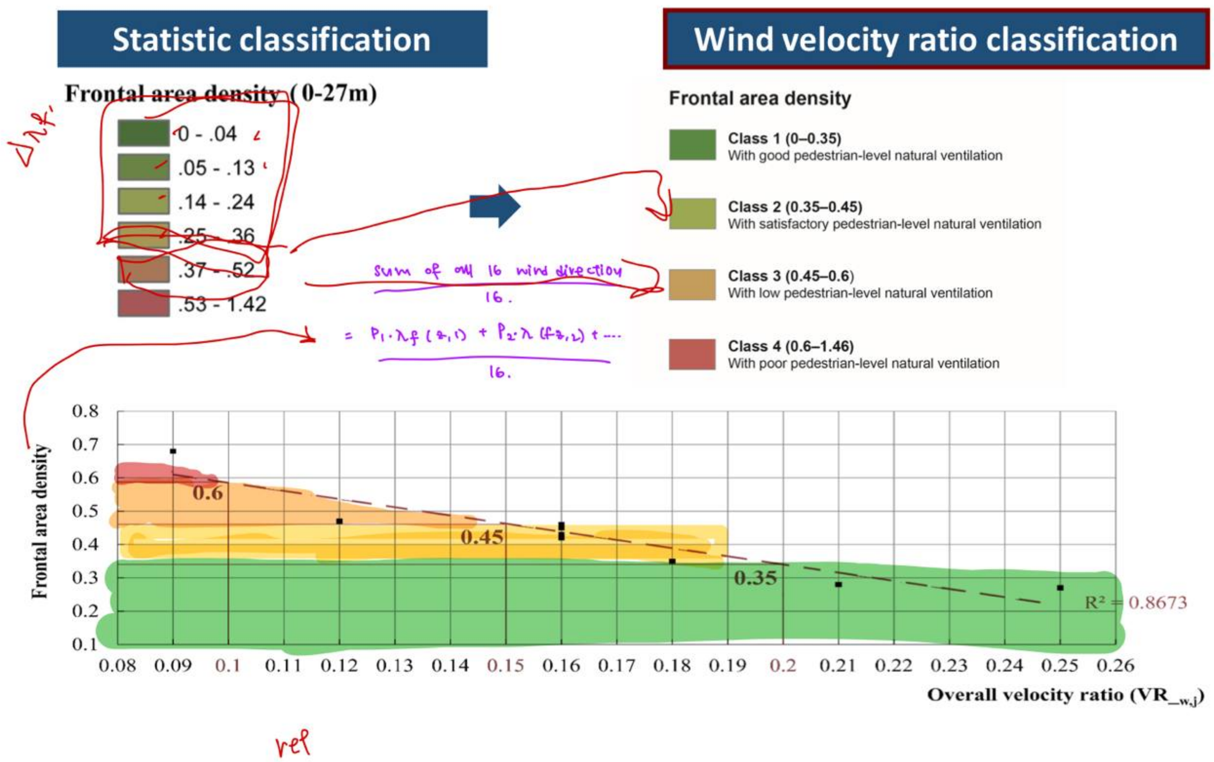


α =Surface roughness

Source: 市街地風環境予測のための流体数値解析ガイドブック －ガイドラインと検証用データベース－ (AIJ guideline)

λf values for urban vs rural areas.

[4] Spatial variability of frontal area index and its relationship with urban heat island intensity



λf values for urban areas to evaluate pedestrian level wind flow.

Method of Analysis:

1. Finding λf values of each subzone

From regression line: y = 0.9021 x + 0.0453
Where y = Ground coverage ratio (Built area/ Site area),
And x = Urban Surface Roughness Index (λf)

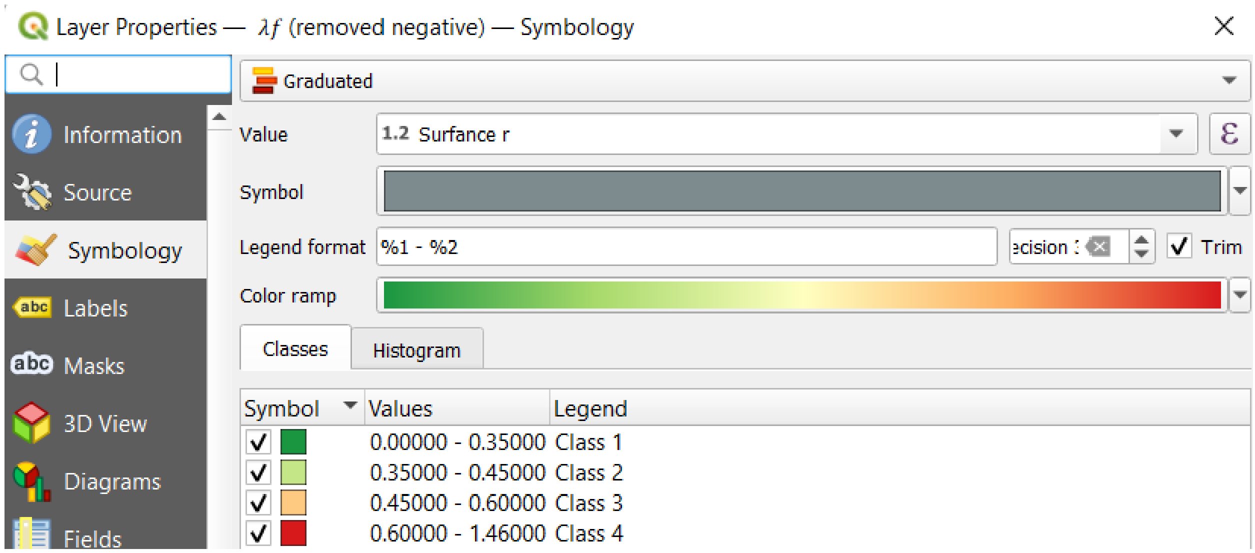
To get attribute of x (λf),
X = (y - 0.0453) / 0.9021

SUBZONE_NO	SUBZONE_N	SUBZONE_C	CA_IND	PLN_AREA_N	PLN_AREA_C	REGION_N	REGION_C	INC_CRC	FMEL_UP	nippe	area	bldgare	bldgdns	Surfance r
2	SWISS CLUB	BTSZ02	N	BUKIT TIMAH	BT	CENTRAL REGI...	CR	DE0B35BEB9BB...	20191223152313	NULL	3484059.71946...	396946.0526375088375...	0.11393204611...	0.076

The accuracy of the results might be affected by:

- Regression line is formed by analysis individual buildings, but we used it to get λf of subzones
- About 40 low negative values were returned, ranging from -0.05 to 0
- λf values cannot be negative, due to sea/ water surface having a value of λf = 0.1

2. Categorising λf values to wind velocity classification ratio



Green: low λf, low surface roughness, low friction, high pedestrian level wind flow
Red: High λf, highl surface roughness, high friction, low pedestrian level wind flow

Skimming Wind analysis
Overlayed with Urban Surface Roughness Map
Week 4

- Checked with Prof YC, no need to go back to λf, can directly get wind velocity from GCR Values

Identify areas of high density (density map)

Put grid (90 x 90m)

In grids that fall under high density areas, (AREA H) do a stand dev of building heights. (high/ low variance of building heights in the area)
>> get: areas with high risk of skimming wind

To get pedestrian level wind flow conditions
- in (AREA H)
- Do GCR for each grid
- Use regression line between GCR and average wind velocity
- Use v = U ref / U pedestrian to get pedestrian level wind speed

>> get: areas with low windspeed

areas with high risk of skimming wind overlapped with areas with low windspeed

>>get: areas of low thermal comfort levels, can be improved by strategies of improving building height variations.

3. Pedestrian Level Wind Velocity Map (Upedes)

Goal: to look for areas with Low Pedestrian Level Wind Speed >> Low Air Flow >> Low Thermal Comfort

Cross check with: (to identify relationships)

- Average surface temperature/ UHI (to cross check with average surface temperature)
- Skimming wind map (to cross check on accuracy, ie. some areas of high skimming wind flow should correspond to low wind speed)
- Actual absolute values from weather stations (for accuracy)

Method of Analysis:
Find GCR (%) of each grid, then use the regression line to find values of pedestrian level wind speed.
>> get: areas with low pedestrian level wind speed

Steps:

1. Getting GCR (building footprint area / Grid area)

- Overlay grid on top of SG Building footprint with landuse.

Building FP attribute table:

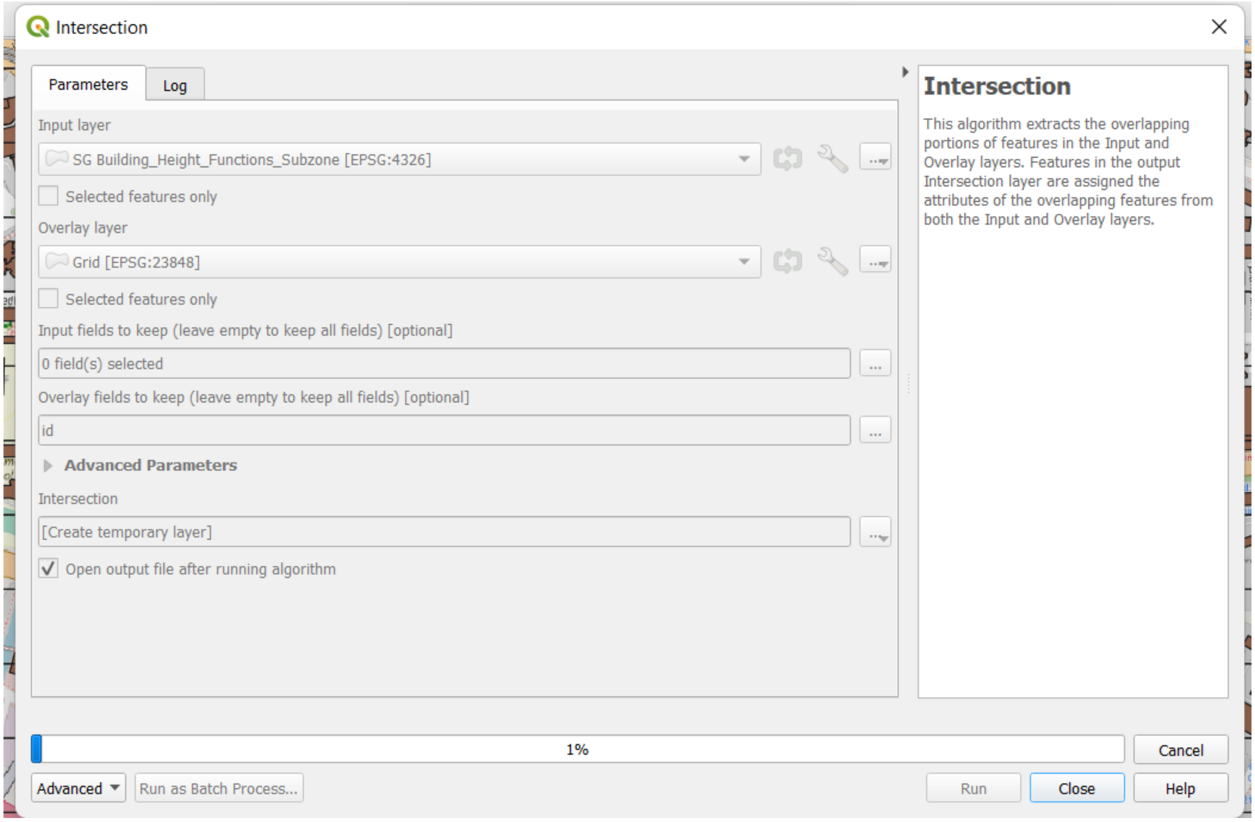
	fid	id	height	Floors	Building a	GFA	LU_DESC	SUBZONE_N	PLN_AREA_N
1	11598	osm-w174717963	17.0000000000...	6	1157.76299999...	6946.57800000...	RESERVE SITE	MARINA EAST	MARINA EAST
2	11600	osm-w174717967	5.00000000000...	2	175.699000000...	351.398000000...	RESERVE SITE	MARINA EAST	MARINA EAST
3	11601	osm-w174717980	3.00000000000...	1	872.245000000...	872.245000000...	RESERVE SITE	MARINA EAST	MARINA EAST
4	106873	osm-w547145123	5.00000000000...	2	553.691000000...	1107.38200000...	RESERVE SITE	MARINA EAST	MARINA EAST

Grid attribute table:

	id	left	top	right	bottom
1	1	344838.754459...	162611.113414...	344928.754459...	162521.113414...
2	2	344838.754459...	162521.113414...	344928.754459...	162431.113414...
3	3	344838.754459...	162431.113414...	344928.754459...	162341.113414...

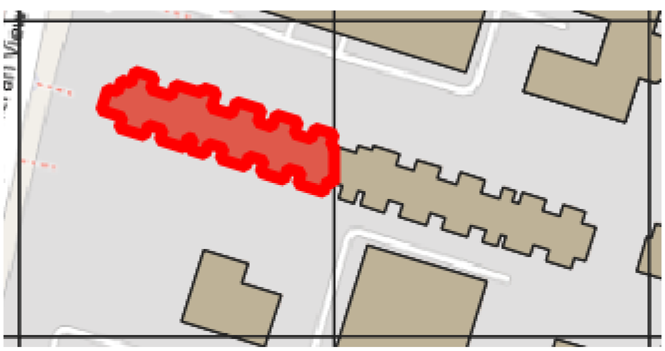
2. Intersect Building FP with Grid

- Vector >> Geoprocessing tools >> Intersection



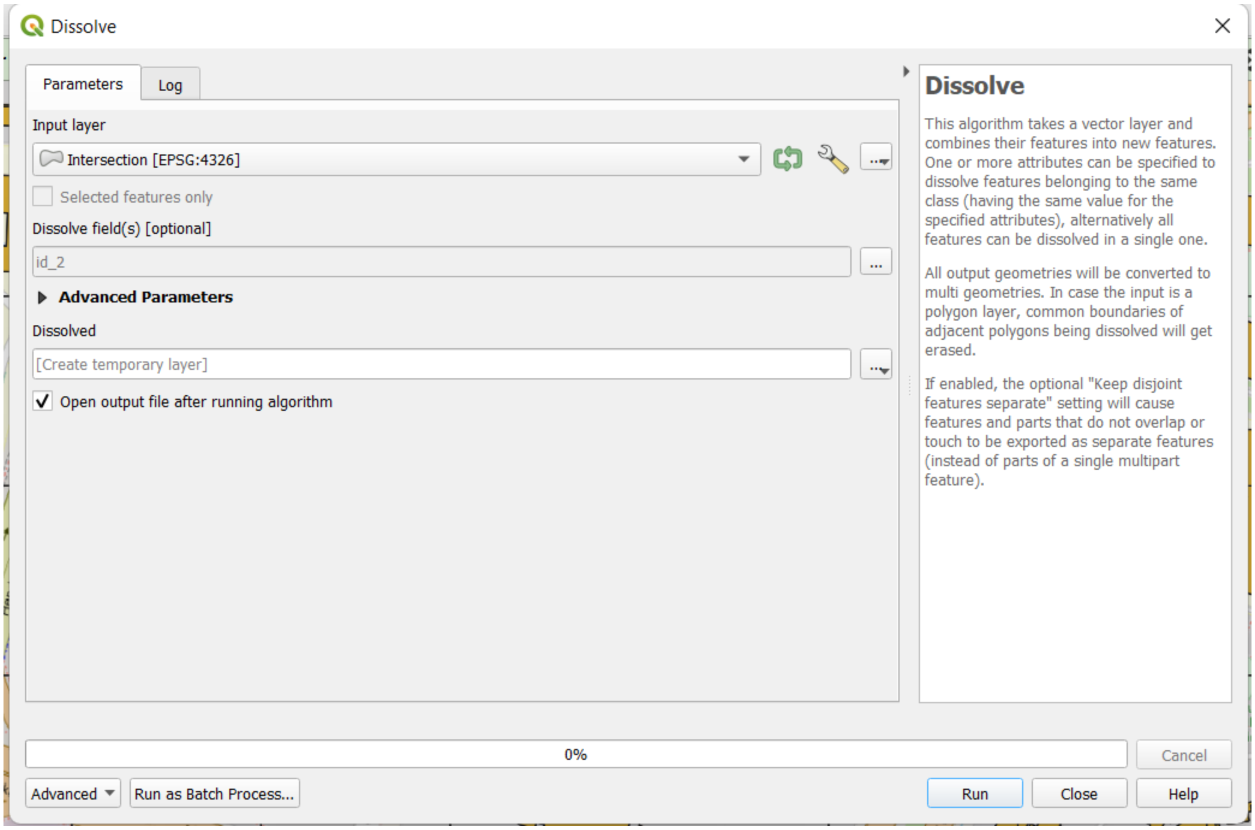
Result: grid ID added to Building FP attribute table, Building FP is cut by grid line

	fid	id	height	Floors	Building a	GFA	LU_DESC	SUBZONE_N	PLN_AREA_N	id_2
1	11598	osm-w174717963	17.0000000000...	6	1157.76299999...	6946.57800000...	RESERVE SITE	MARINA EAST	MARINA EAST	126171
2	11598	osm-w174717963	17.0000000000...	6	1157.76299999...	6946.57800000...	RESERVE SITE	MARINA EAST	MARINA EAST	126172
3	11600	osm-w174717967	5.00000000000...	2	175.699000000...	351.398000000...	RESERVE SITE	MARINA EAST	MARINA EAST	125787
4	11600	osm-w174717967	5.00000000000...	2	175.699000000...	351.398000000...	RESERVE SITE	MARINA EAST	MARINA EAST	126171

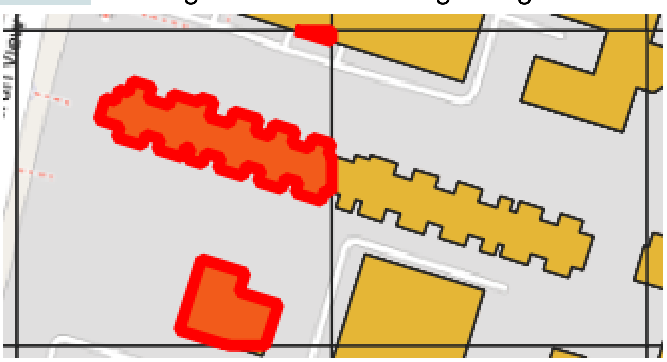


3. Dissolve based on grid

- Vector >>Geoprocessing tools >> Dissolve



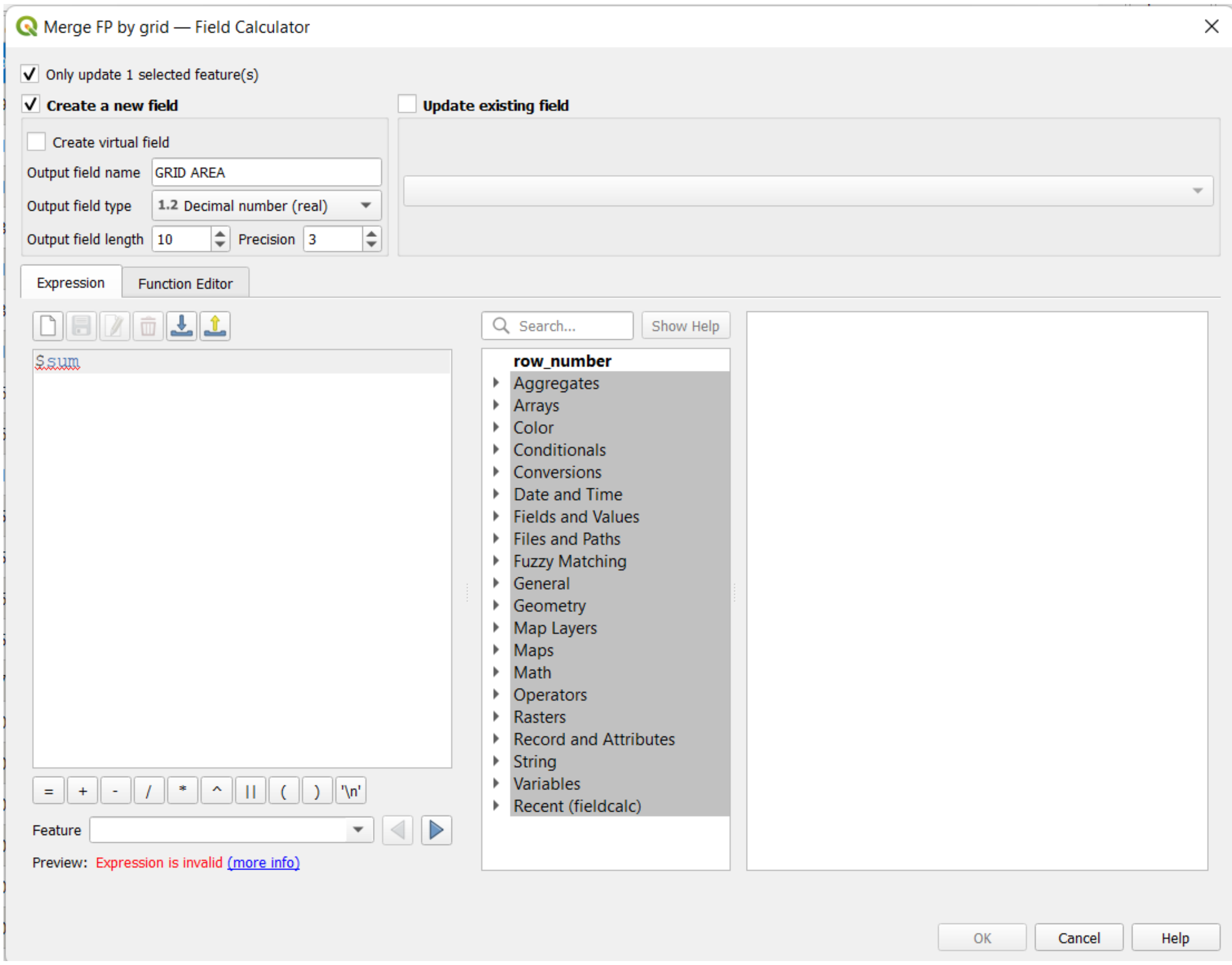
Result: building FP areas are merged together.



4. Calculate GCR (%)

- Create New Field: “Grid area” via Attribute table >> Field calculator

Input: $area

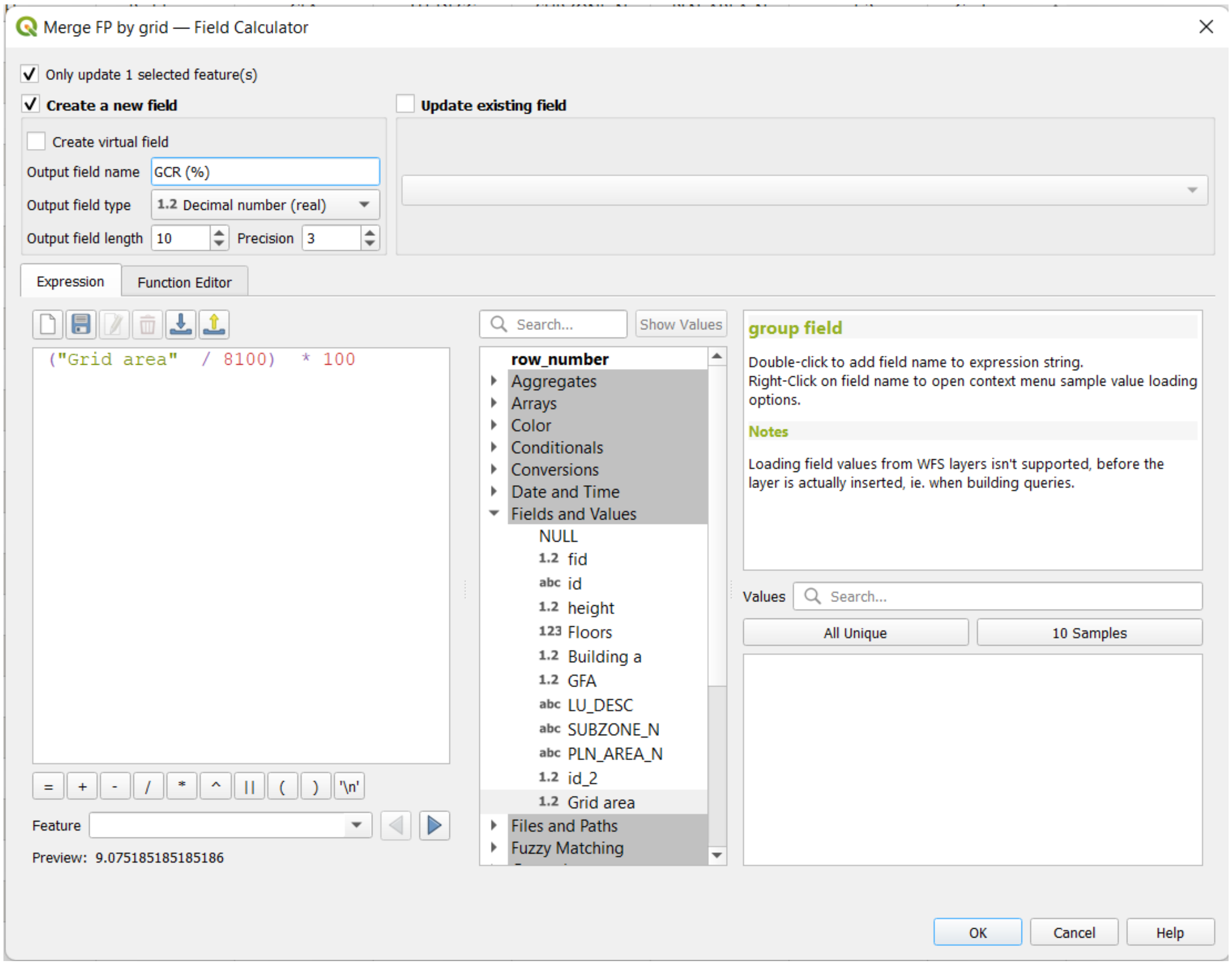


Result: grid area column is created in the attribute table

	fid	id	height	Floors	Building a	GFA	LU_DESC	SUBZONE_N	PLN_AREA_N	id_2	Grid area
34	35941	osm-w111700662	3.00000000000...	1	5004.72299999...	5004.72299999...	SPORTS & RECR...	LIM CHU KANG	LIM CHU KANG	58041	0.019
35	54354	SG-0003809	9.00000000000...	3	145.323000000...	435.968999999...	NULL	NULL	NULL	125400	0.022
36	7289	osm-w188187759	3.00000000000...	1	57.7620000000...	57.7620000000...	BUSINESS 2	PASIR RIS WAFE...	PASIR RIS	151007	0.022
37	71114	osm-w965301174	3.00000000000...	1	233.038999999...	233.038999999...	TRANSPORT FA...	MANDAI WEST	MANDAI	88765	0.023

- Create New Field: “GCR (%)” via Attribute table >> Field calculator

Input: ("Grid area" / 8100) * 100

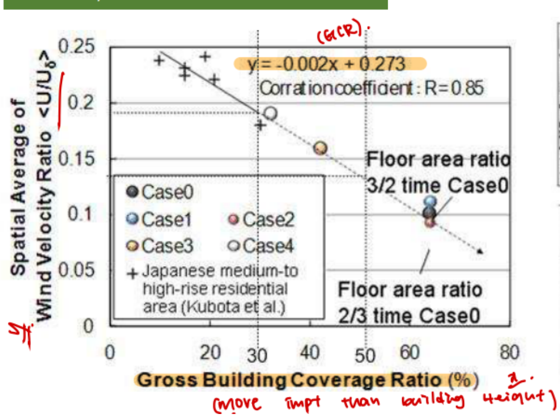


Result: "GCR (%)" column is created in the attribute table

fid	id	height	Floors	Building a	GFA	LU_DESC	SUBZONE_N	PLN_AREA_N	id_2	Grid area	GCR (%)
1	osm-r2241095	5.00000000000...	2	24244.2959999...	48488.5919999...	NULL	PORT	QUEENSTOWN	89716	4705.408	58.091
1	osm-r2241095	5.00000000000...	2	24244.2959999...	48488.5919999...	NULL	PORT	QUEENSTOWN	90099	525.604	6.489
1	osm-r2241095	5.00000000000...	2	24244.2959999...	48488.5919999...	NULL	PORT	QUEENSTOWN	90486	0.878	0.011

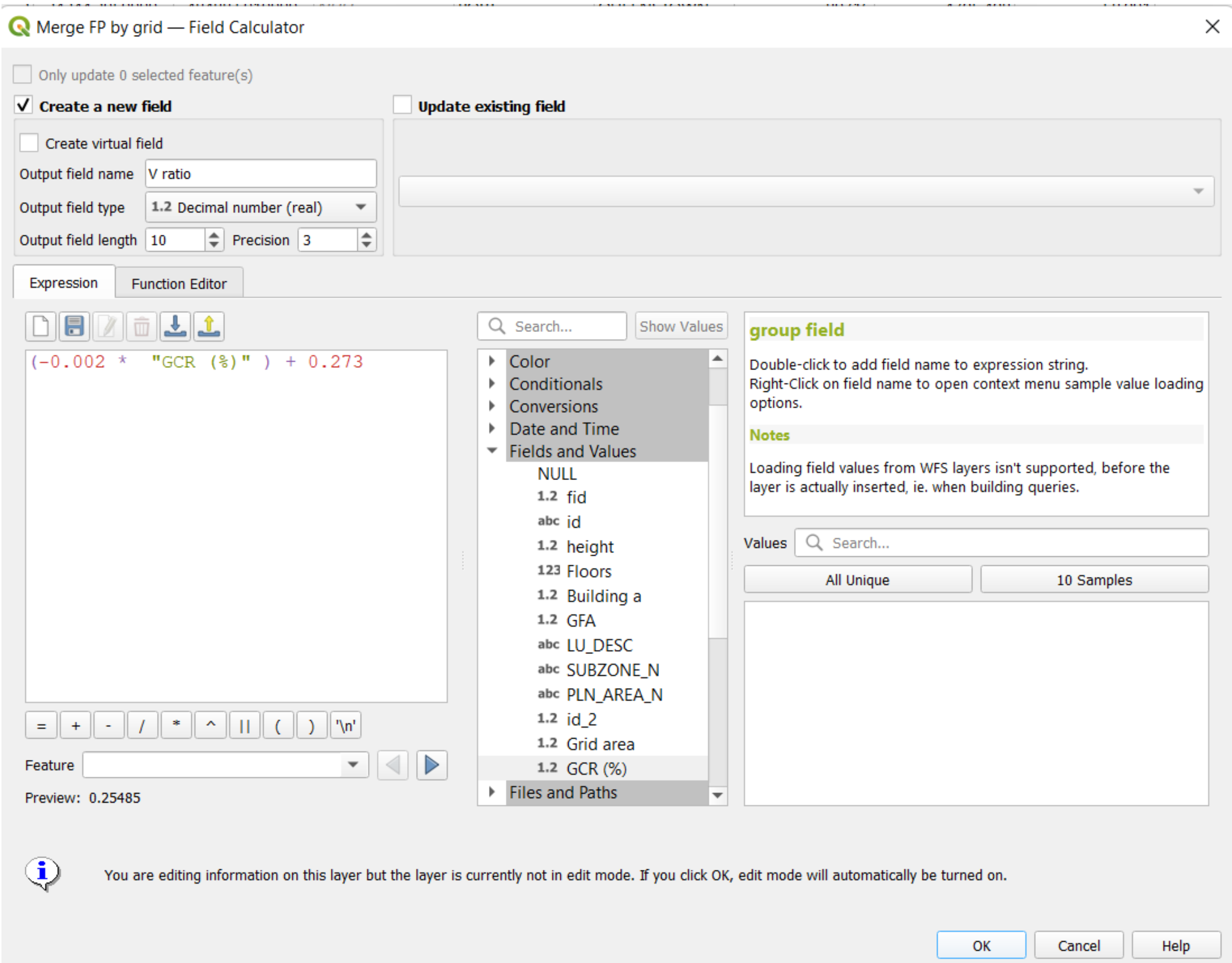
5. Calculate Pedestrian level wind speed (Up)

Relationship between Gross Building Coverage Ratio and Wind Velocity Ratio



- Since there is a strong correlation between Spatial Average Wind Velocity ratio <U/Up>(y) and Gross Building Coverage Ratio % (x), R= 0.85, we can use: y = -0.002x + 0.273 to approximate the Wind velocity ratio for each grid.

- Create New Field: “V ratio” via Atrribute table >> Field calculator



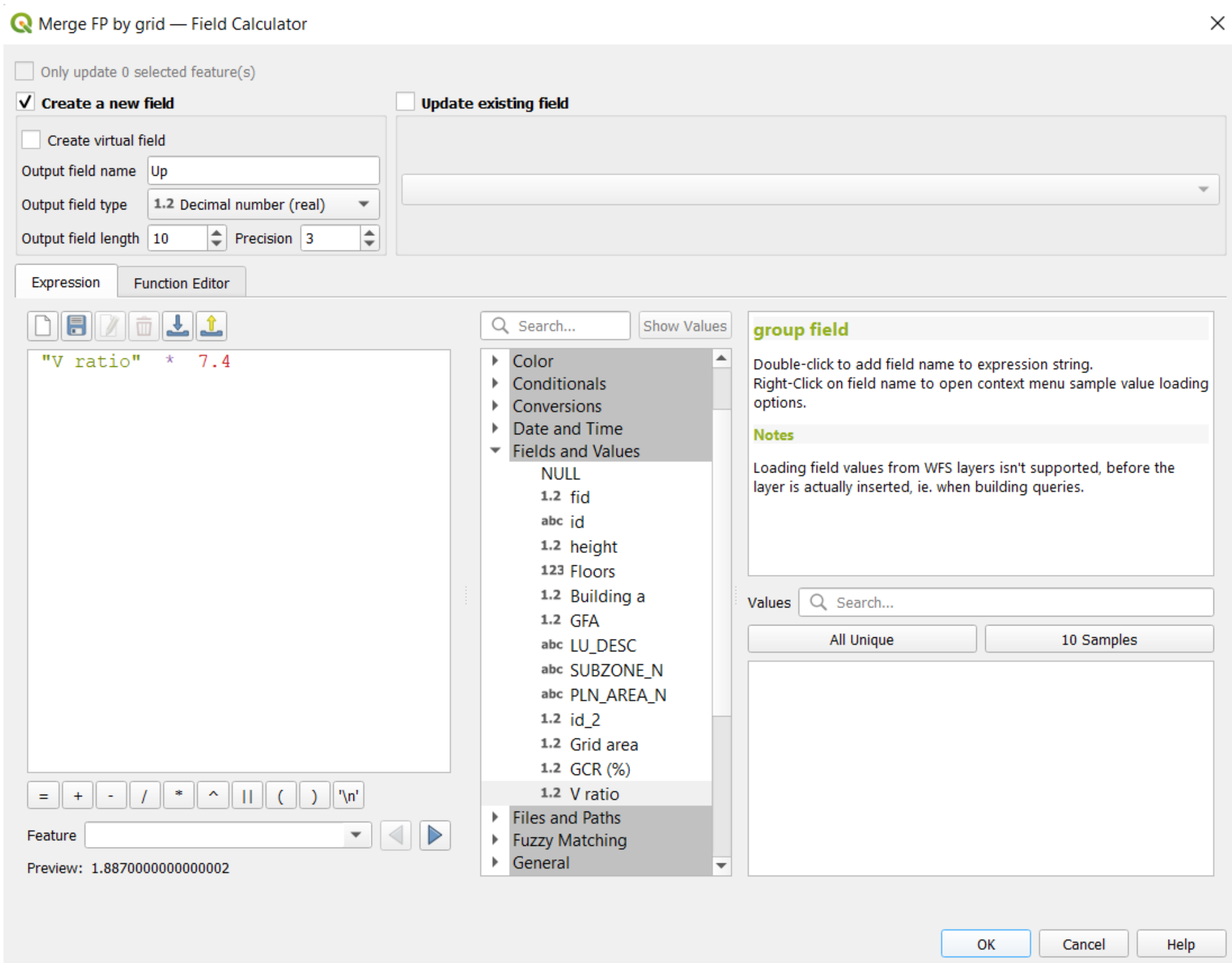
Result: “V ratio” column is created in the attribute table

fid	id	height	Floors	Building a	GFA	LU_DESC	SUBZONE_N	PLN_AREA_N	id_2	Grid area	GCR (%)	V ratio
1	osm-r2241095	5.00000000000...	2	24244.2959999...	48488.5919999...	NULL	PORT	QUEENSTOWN	89716	4705.408	58.091	0.157
1	osm-r2241095	5.00000000000...	2	24244.2959999...	48488.5919999...	NULL	PORT	QUEENSTOWN	90099	525.604	6.489	0.26
1	osm-r2241095	5.00000000000...	2	24244.2959999...	48488.5919999...	NULL	PORT	QUEENSTOWN	90486	0.878	0.011	0.273

- since V ratio = Average wind speed at pedestrian level (Up) / Average wind speed at Reference level (7.4 m/s)

Up (m/s) = v ratio * 7.4m/s

- Create New Field: “Up” via Atrribute table >> Field calculator

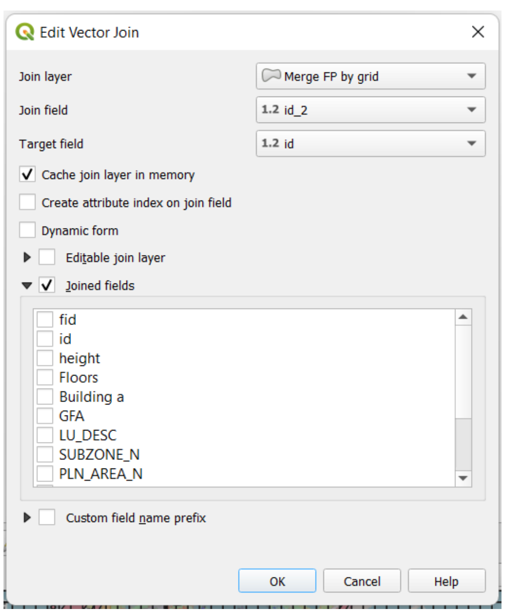


Result: “Up” column is created in the attribute table

fid	id	height	Floors	Building a	GFA	LU_DESC	SUBZONE_N	PLN_AREA_N	id_2	Grid area	GCR (%)	V ratio	Up
1	osm-r2241095	5.00000000000...	2	24244.2959999...	48488.5919999...	NULL	PORT	QUEENSTOWN	89716	4705.408	58.091	0.157	1.162
1	osm-r2241095	5.00000000000...	2	24244.2959999...	48488.5919999...	NULL	PORT	QUEENSTOWN	90099	525.604	6.489	0.26	1.924
1	osm-r2241095	5.00000000000...	2	24244.2959999...	48488.5919999...	NULL	PORT	QUEENSTOWN	90486	0.878	0.011	0.273	2.020

6. Map Up back to the grid and reflect results

- Grid >> Properties >> Joins



Result: “Up” column is added to the attribute table of “Grid” layer

	id	left	top	right	bottom	Merge FP by grid_Up
1	307	344838.754459...	135071.113414...	344928.754459...	134981.113414...	2.020
2	1804	345198.754459...	138581.113414...	345288.754459...	138491.113414...	2.020
3	2190	345288.754459...	138401.113414...	345378.754459...	138311.113414...	2.020

- The final results of Up are then classified by the Beaufort Scale (Human Version) table:

WIND CLASSIFICATION

NUS | DOA ARCHITECTURE | UCDL

* below 0.3 m/s → human body cannot feel air flow.

* numbers are important to check CFD results *

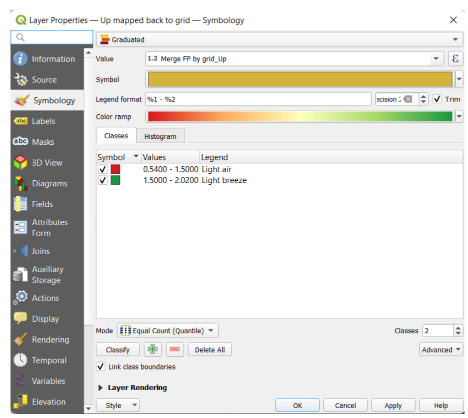
Beaufort Scale (Human version)

0	1	2	3	4	5	6	7	8	9	10	11	12
Calm	Light Air	Light Breeze	Gentle Breeze	Moderate Breeze	Fresh Breeze	Strong Breeze	Near Gale	Gale	Strong Gale	Storm	Violent Storm	Hurricane Force
Light Winds						High Winds		Gale-force		Storm-force		Hurricane -force
<0.3 m/s	0.3–1.5 m/s	1.6–3.3 m/s	3.4–5.5 m/s	5.5–7.9 m/s	8.0–10.7 m/s	10.8–13.8 m/s	13.9–17.1 m/s	17.2–20.7 m/s	20.8–24.4 m/s	24.5–28.4 m/s	28.5–32.6 m/s	≥32.7 m/s
Calm, no noticeable wind	Noticeable wind	Wind felt on face	Wind extends light flag Hair is disturbed	Raises dust, dry soil and loose paper ... ang	Force of wind felt on body Drifting snow becomes airborne Limit of agreeable wind on land	Umbrellas used with difficulty Hair blown straight Difficult to walk steadily Wind noise on ears unpleasant Windbor ... head height (blizzard)	Inconvenience felt when walking	Generally impedes progress Great difficulty with balance in gusts	People blown over by gusts			

Thermal Comfort

Wind power

Wind Load



Result:

Wind speeds are separated into 3 categories

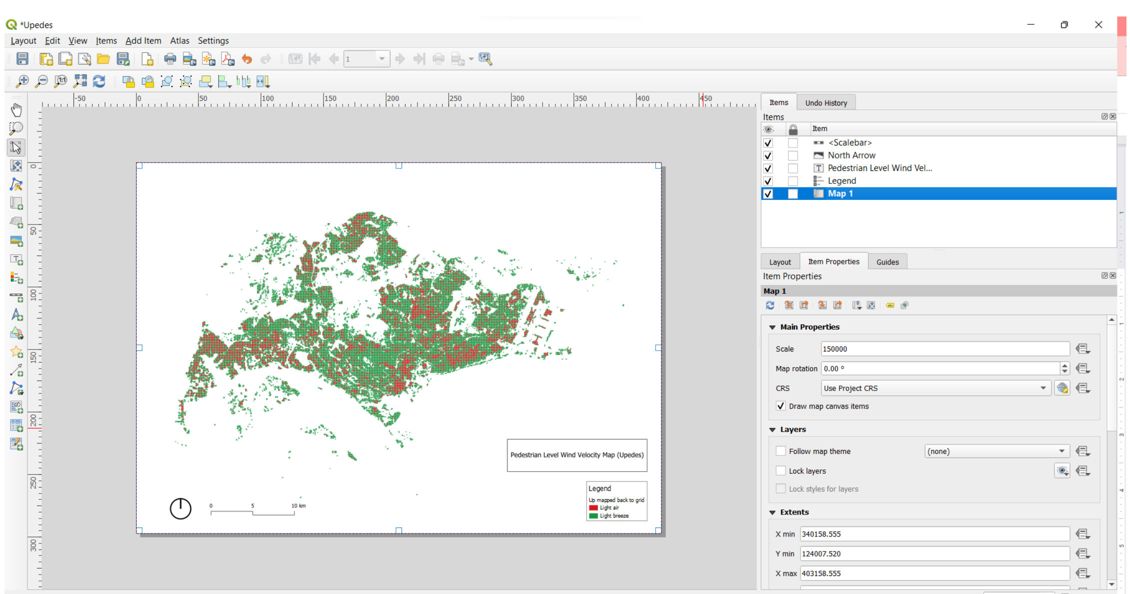
- White: Zero (no Building FP)
- Red: (0.54 - 1.5 m/s)

Light air (values starts from 0.54) - areas of low thermal comfort

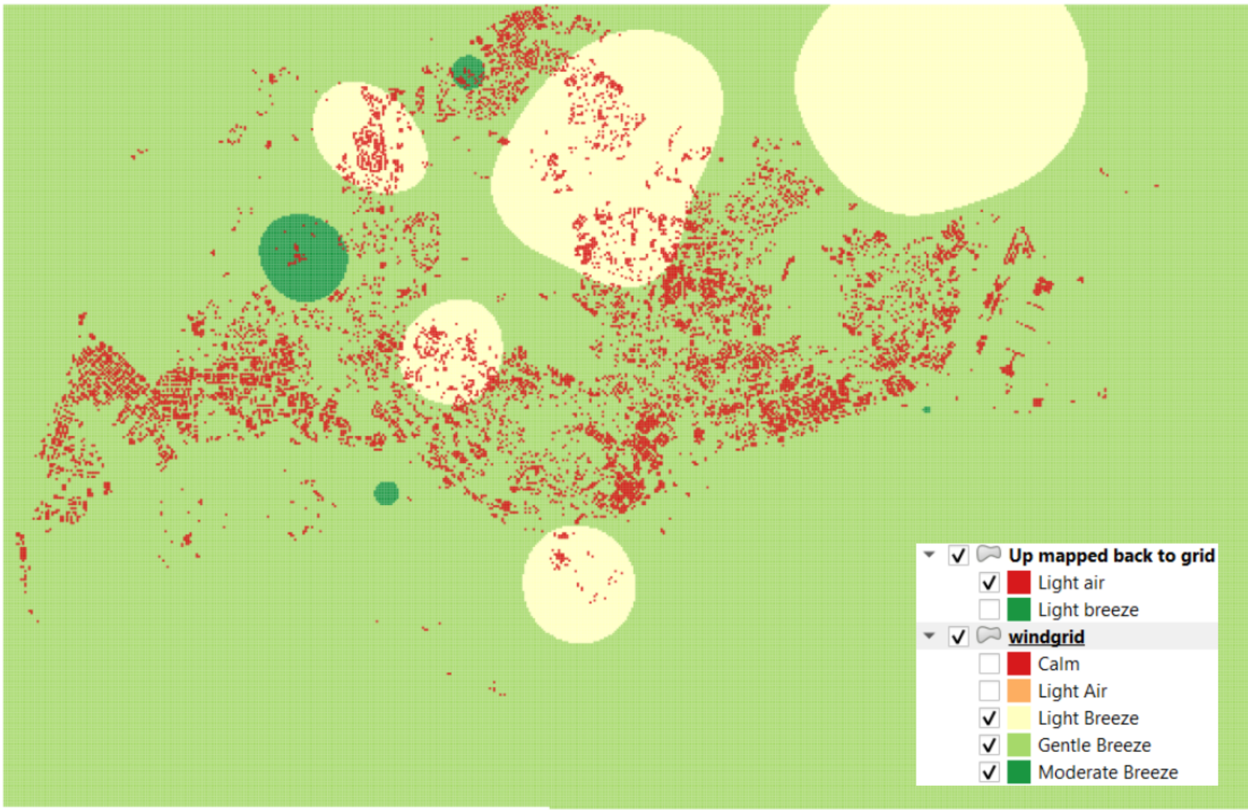
- Green: (1.5 - 2.02 m/s)

Light breeze (valyes end at 2.02) - areas of higher thermal comfort

7. Layout Settings

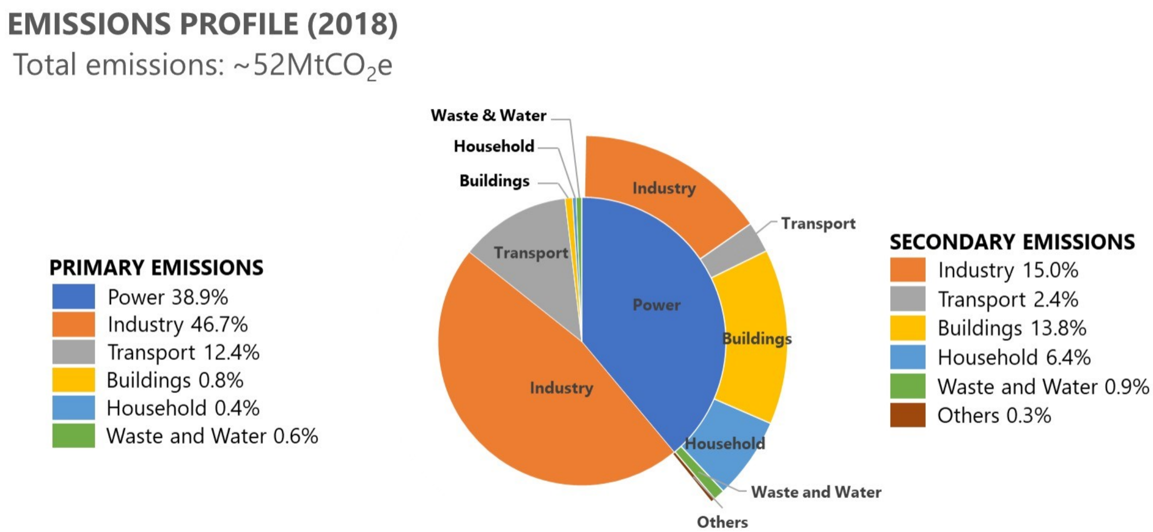


4. Skimming Wind Map Overlayed with U_{pedes} Map



Up with actual wind speed values overlaid on top.

1. Carbon Emission Analysis



Map

Goal: to look for areas with high emission index (/MKgCO2e) based on Overall Singapore Carbon Emission Data (2018) >> Possible sites to reform landuse/ ratio of Higher emission to lower emission buildings

Areas with high emission index (/MKgCO2e) could also mean larger amount of Green House Gas in the area >> High Anthropogenic Heat in the area due to their ability to trap heat

Cross check with: (to identify relationships)

- Average surface temperature/ UHI (to cross check with average surface temperature)
- Energy Consumption (Increased energy usage lead to Increased emissions)

Method of Analysis:

1. Merge URA Landuse Map Data with “Building Footprint + Height”
2. Calculate GFA
3. Calculation of Total Carbon Emissions by sector (absolute values)
4. Reduce data analysis area to “New Site Boundary”

[5]

Taking reference from Total Singapore Carbon Emissions by Sector statistics from 2018, we begin relating each type of landuse in the URA Landuse Map.

Buildings (0.8% + 13.8%) = 14.6% ≈ 7.592MtCO2e
Land use under “Buildings” = CIVIC & COMMUNITY INSTITUTION + COMMERCIAL + COMMERCIAL / INSTITUTION + EDUCATIONAL INSTITUTION + HEALTH & MEDICAL CARE + HOTEL + PLACE OF WORSHIP + SPECIAL USE + SPORTS & RECREATION + TRANSPORT FACILITIES + UTILITY + RESIDENTIAL / INSTITUTION + RESIDENTIAL + RESIDENTIAL / COMMERTIAL

7.592MtCO2e / Total GFA of all buildings (excluding “industry) ≈ 0.0000169853849421 MKgCO2e/m2 (emission per 1 m2 of “Buildings”)

(0.0000169853849421 * 1000) * GFA of each building under “Buildings” (except “Household”)

Household (0.4% + 6.4%) = 6.8% ≈ 3.536MtCO2e
Land use under “Household” = RESIDENTIAL / INSTITUTION + RESIDENTIAL + RESIDENTIAL / COMMERTIAL

3.536MtCO2e/ Total GFA of “Household” buildings ≈ 0.00001543167706265 MKgCO2e/m2 (emission per 1 m2 of “Household” buildings)

((0.00001543167706265 + 0.0000169853849421) * 1000) * GFA of each building under “Household”

Industry (46.7% + 15.0%) = 61.7% ≈ 32.084MtCO2e
Land use under “Industry” = BUSINESS 1 + BUSINESS 2 + BUSINESS PARK

[5] https://www.nccs.gov.sg/singapores-climate-action/singapore-emissions-profile/

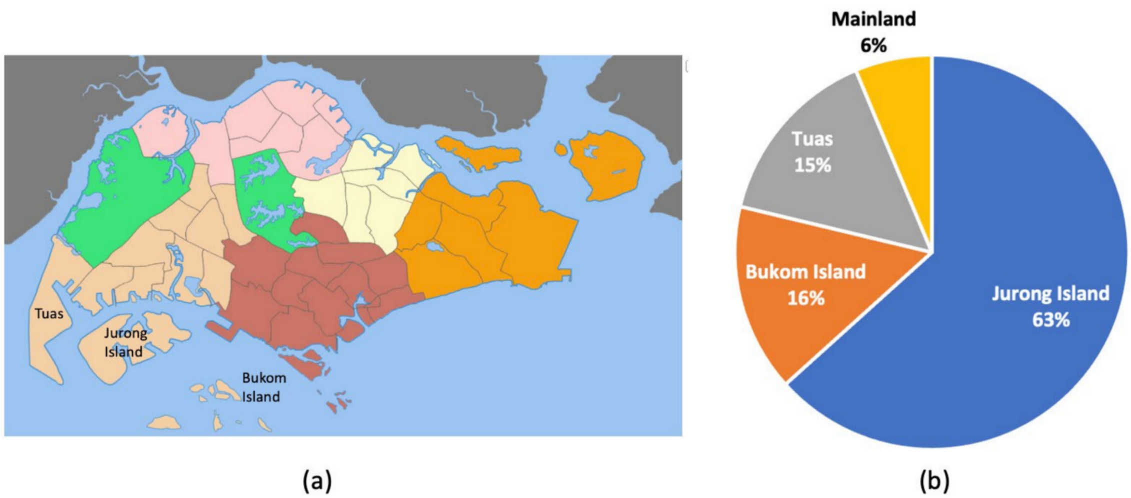


Figure 3. (**a**) Map of Singapore, (**b**) CO_2 emissions from industry and power by location. [6]

“Industry” in Jurong Island + Buokm Island = 63% + 16% = 79%
79% of 32.084MtCO2e ≈ 25.256 MtCO2e

“Industry” in Tuas = 15%
15% of 32.084MtCO2e ≈ 4.813 MtCO2e

“Industry” in Mainland = 6%
32.084MtCO2e - 25.256 MtCO2e - 4.813 MtCO2e = 2.671 MtCO2e

2.671 MtCO2e / Total GFA of “Industry” buildings in Jurong Island + Buokm Island ≈ — MKgCO2e/m2 (emission per 1 m2 of “Household” buildings)

2.671 MtCO2e / Total GFA of “Industry” buildings in Tuas ≈ — MKgCO2e/m2 (emission per 1 m2 of “Household” buildings)

2.671 MtCO2e / Total GFA of “Industry” buildings in Mainland ≈ — MKgCO2e/m2 (emission per 1 m2 of “Household” buildings)

[6] A Decarbonization Roadmap for Singapore and Its Energy Policy Implications