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BUILDING PHYSICS AND ENVIRONMENT
CAFÉ DESIGN
COURSEWORK

Introduction

This design is aimed at producing an environmental design for a low energy, passive ventilated and beachside café. The café is oriented with the South side facing the beach with the wind direction blowing from the South East. The road is located 40m to the North of the café. The café is capable of seating 24 customers along with 2 serving staff in a total seating area of 99 square metres. The opening hours of the café are 9:00 – 23:00 i.e., its open all day and evenings. Since the café is open all year round it is essential to make it suitable for year-round environmental conditions.

1. VENTILATION & THERMAL COMFORT ASSESSMENT

a) Natural Ventilation Strategy

- The café is ventilated mainly using natural ventilation with mechanical ventilation used in some parts where natural ventilation is not appropriate.
- The café is divided into a seating space, two toilets and a kitchen.
- SEATING SPACE:
  - The primary ventilation strategy for the seating space is of natural ventilation through cross ventilation through openings.
  - However, since cross ventilation relies completely on the effect of wind, which is unpredictable and unreliable an alternative source of ventilation is required.
  - An alternate stack ventilation system is installed in the seating space which operates through a stack chimney and existing openings for cross ventilation.
  - The stack chimney is to remain closed at times the wind is sufficient to solely ventilate the space and shall be opened when the wind in insufficient with the aid of a sensor.
- TOILETS:
  - The toilets are ventilated through a single opening on the east wall and hence the strategy adapted it the single sided ventilation through a single opening
- KITCHEN:
  - Since the kitchen produces a large amount of CO_2 , heat as well as food odours it is predominantly mechanically ventilated.
  - However, some natural ventilation through cross ventilation has been added in order to maintain thermal comfort.
  - Two mechanical ventilation extracts have been provided in the kitchen. The first in the geometric centre of the kitchens roof and the second above the main cooking station.

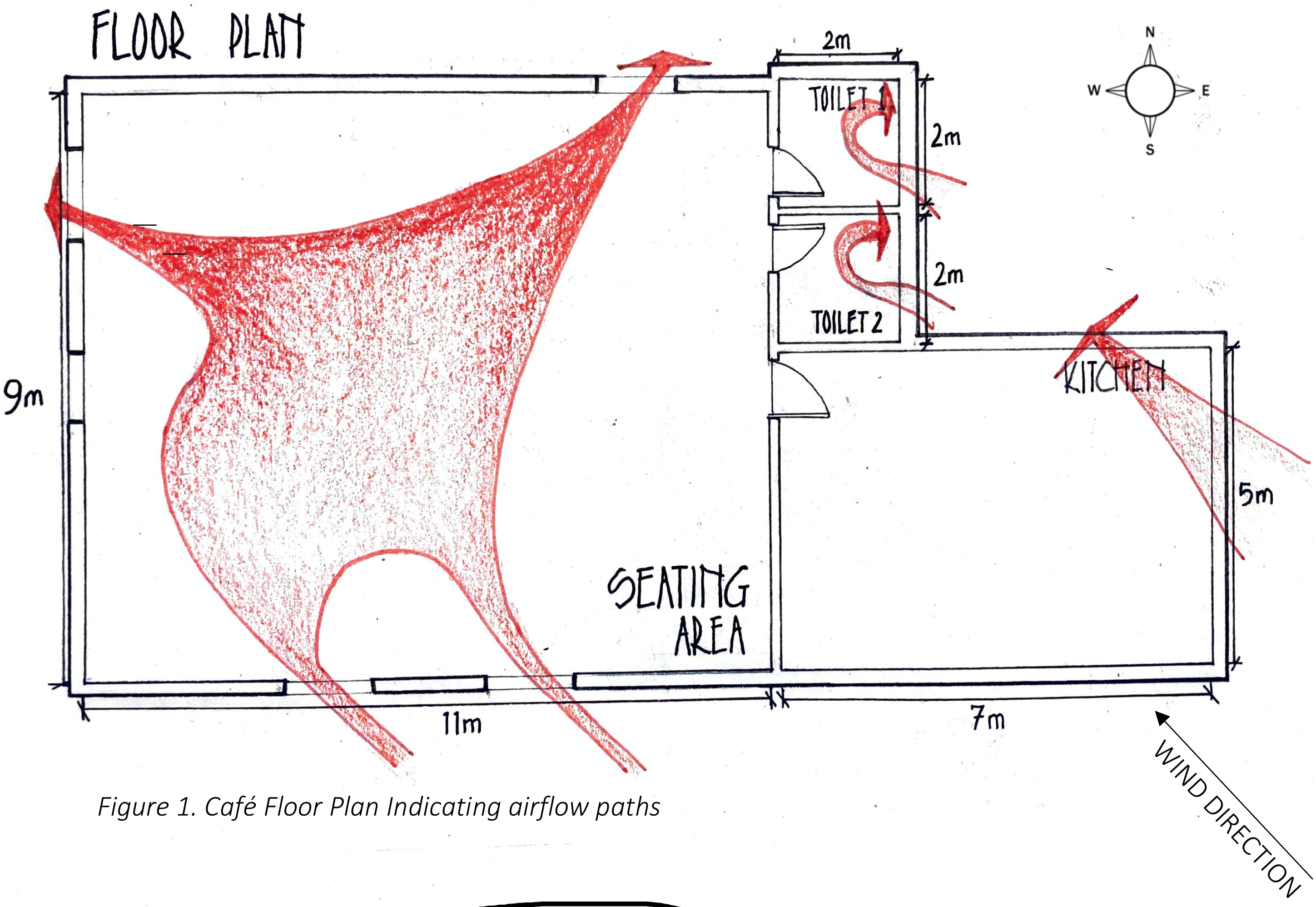


Figure 1. Café Floor Plan Indicating airflow paths

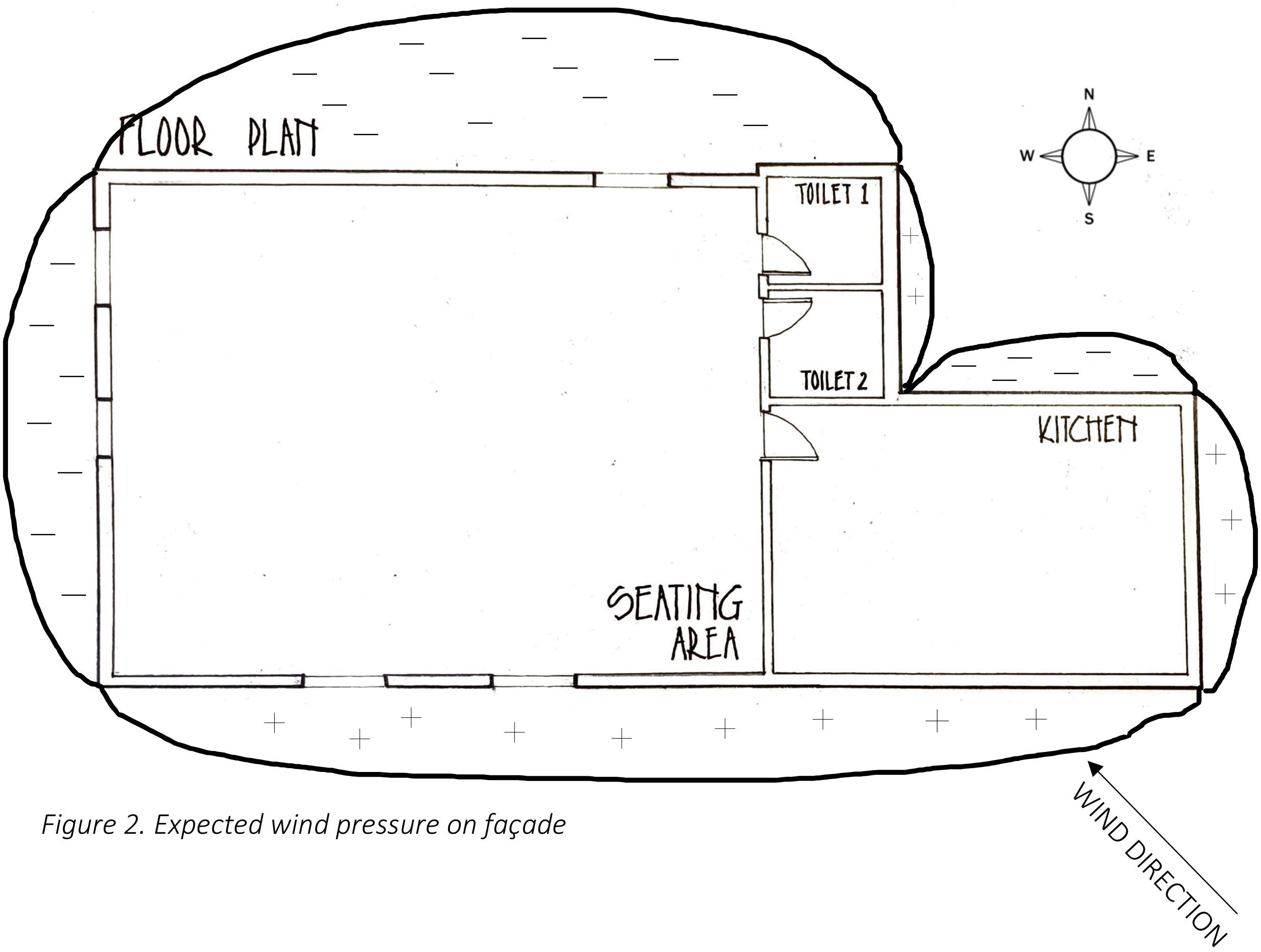


Figure 2. Expected wind pressure on façade

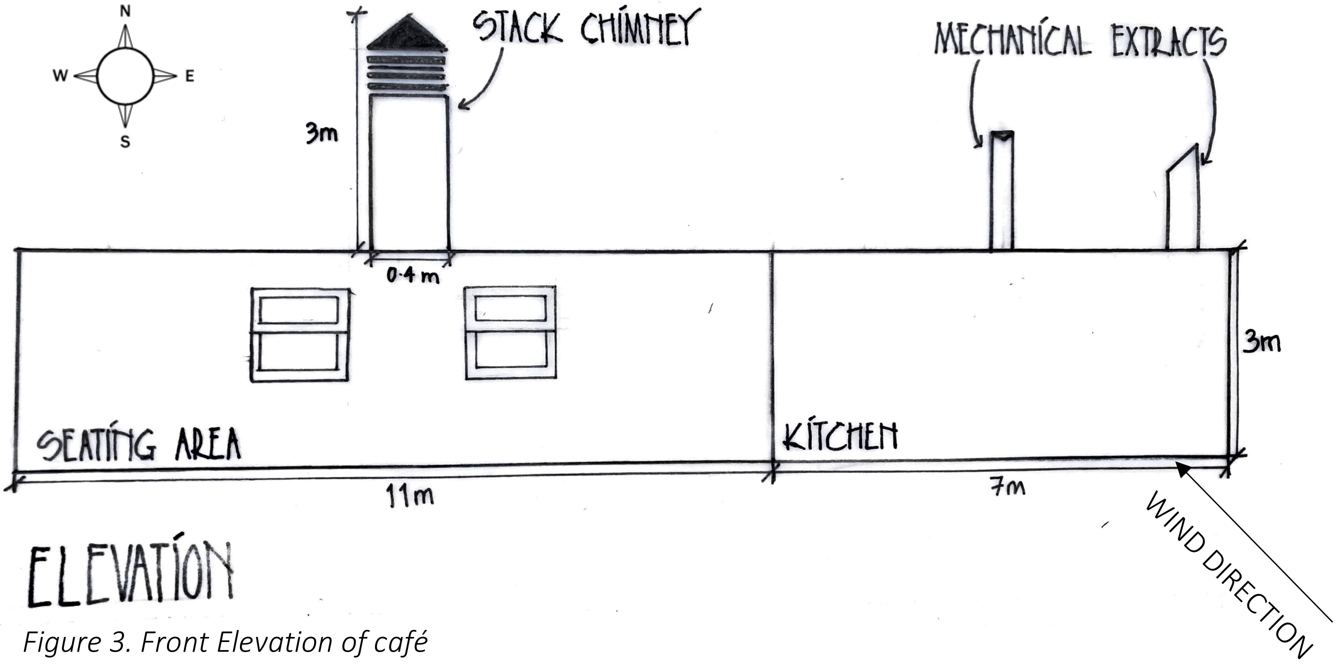


Figure 3. Front Elevation of café

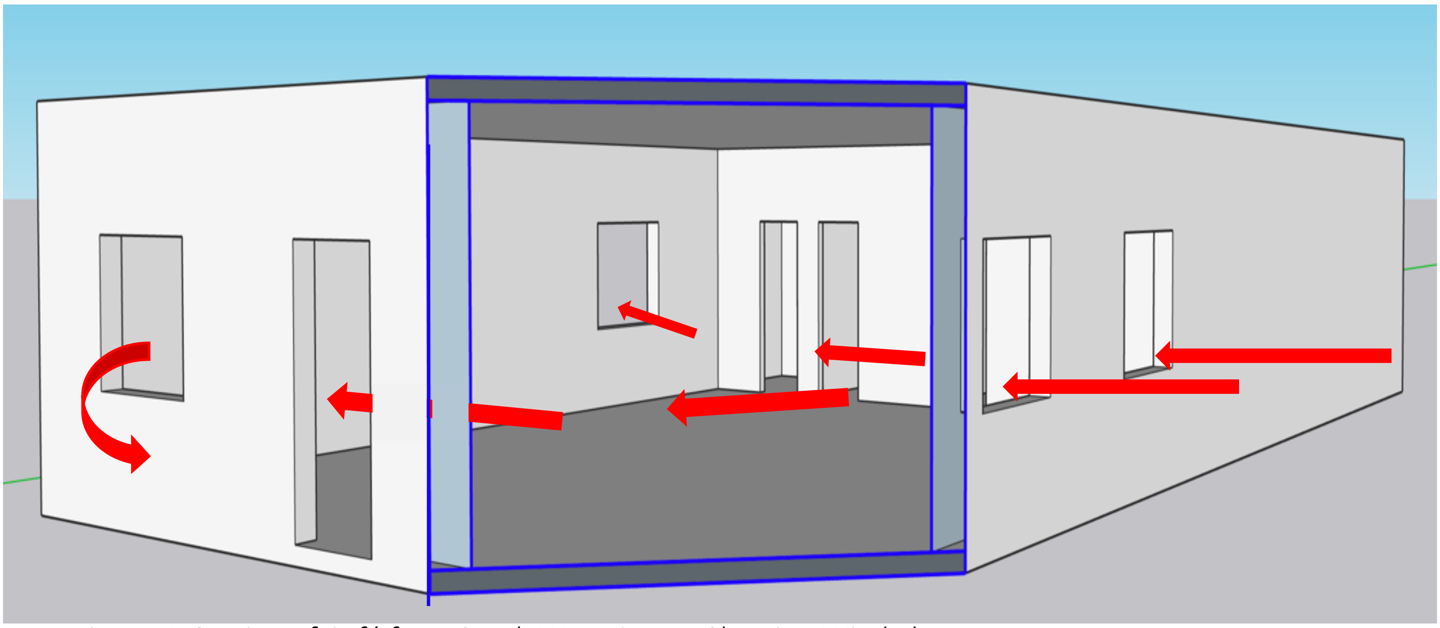


Figure 4. Section of Café from South West Corner Showing Wind Flows

- SHORTCOMINGS:
    - The alternative stack ventilation system works when the wind is not sufficient enough to carry out cross ventilation. In calculating stack openings however, it has been assumed that there is no wind flowing when stack is operating (for simplification) which may not always be the case. Thus, the stack opening sizes do not take into account the effect of wind on stack.
    - The strategy relies heavily on sensors in order to change opening sizes and switch from cross to stack ventilation and hence there is potential risk of failure if the sensors don’t function adequately.
    - Since the wind data of the area was not analysed we cannot estimate the frequency of alternation between stack and cross ventilation (could be too high or too low).

b) Natural Ventilation Envelope Design

- NATURAL VENTILATION IN SEATING AREA:
  - The CIBSE AM10 tool[A] is used to calculate ventilation rates suitable for maintaining CO_2 levels below 1000 ppm which is the given criterion for thermal comfort by CIBSE.

(1) Adjusting Ventilation Rates in order to get desired CO_2 concentrations.

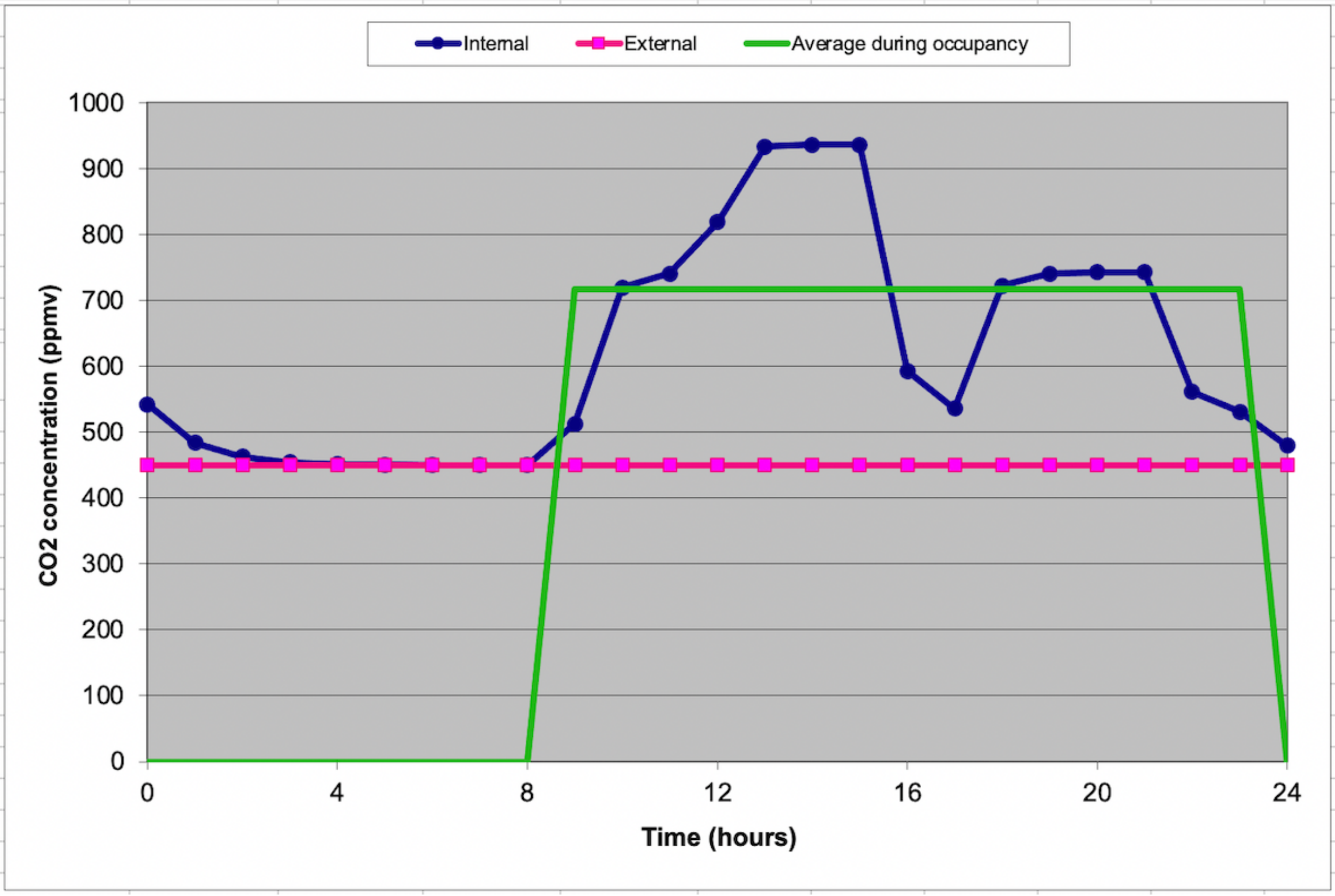
Table 1. Initial Conditions

Room Volume (m^3)	297
CO_2 emission rate (l/hr.p)	20
Initial CO_2 concentration (ppmv)	700

Table 2. Final CO_2 levels achieved

Average Concentration during occupied hours (ppmv)	717.7
Maximum Concentration during occupied hours (ppmv)	936.3
Maximum Deviation from Average	30.5 %

Graph 1. Internal, External and Average (during occupancy) CO_2 concentration over 24 hours in the café



(2) Using required ventilation rates to calculate desired opening sizes.

Table 3. Calculation of opening sizes for required ventilation rate

	26 people	10 people	No people
Required Flowrate (m^3/s)	0.397	0.083	0.190
Wind Speed at building height (m/s)	3.0	3.0	3.0
Discharge Coefficient	0.61	0.61	0.61
Wind Pressure Coefficients [3]			
Windward Side	0.50	0.50	0.50
Leeward Side	-0.20	-0.20	-0.20
Required Area (m^2)	0.367	0.076	0.175

- These openings can be incorporated by opening/closing the following windows.

Table 4. Application of opening sizes into windows on façade

S No.	Façade	Window Dimensions (height x width) [m^2]	Height of Opening [m]	Opening Area [m^2]	Total inflow/outflow opening [m^2]	Target inflow/outflow opening [m^2]
1.	South	1.55 m x 1.5 m	0.15 m	0.225	0.45	0.367
2.	South	1.55 m x 1.5 m	0.15 m	0.225		
3.	West	2 m x 1.5 m	0.15 m	0.225	0.45	0.367
4.	North	1.55 m x 1.5 m	0.15 m	0.225		

- The windows will be single hung windows with single movable sash's. These windows shall be openable in order to change the size of the openings using sensors. For example in minimum occupancy the openings only need to be open a total of 0.076 m^2. (refer to *Figure 3.* for visual representation of windows)

- ALTERNATIVE STACK VENTILATION IN SEATING AREA:
  - The stack chimney opening will remained close until wind is insufficient for cross ventilation. When its insufficient all cross ventilation openings will close and stack chimney will open [1]

$$C_{di} A_i = q_i \sqrt{\frac{T_E + 273}{\Delta T_0 \, g \, L}}$$

Table 5. Data to obtain chimney area

External Temperature (T_E) [°C]	25
Temperature Difference (ΔT_0) [K]	3
Required Flowrate (q_i) [m^3/s]	0.397
Gravitational Acceleration (g) [m/s^2]	9.81
Height of Chimney (L) [m]	3
Discharge Coefficient (C_{di})	0.61

$A_i = 1.195\ m^2$

⇨ $A_i \approx 1.2\ m^2$

- Hence, we add a chimney with a cross sectional area of 1.2 m^2 (0.4 m x 3 m) and height of 3 m in the geometric centre of the seating area.
- CONCERNS:
  - The opening sizes are being incorporated in pre-existing windows. With reference to the size of the windows, the size of the maximum opening is very small. Hence, it does not seem economical to have changeable area of openings for different required ventilation rates as this change would be extremely small compared to the window's total area.
  - The strategy involves openings on the North Wall which is on the road-side and hence, would affect the café's acoustic comfort.

c) Thermal Comfort

- The café is located on the beachside and so high levels of humidity are inevitable. However, the café spaces are efficiently naturally ventilated in order to remove excess humidity.
- The primary building material of the café is concrete. Concrete with its high thermal mass gives rise to night time cooling which significantly lower the peak daytime temperatures.
- There are windows on the South façade to incorporate ventilation openings as well as to enjoy the view of the beach. However, since the South façade experiences maximum direct sunlight and could cause glares as well as elevated internal temperatures. Hence the windows should be glazed or blinds/curtains should be introduced to prevent entry of direct sunlight.
- Certain defects in construction, such as, poorly fitting doors and windows or open chimneys or open doors or windows can cause draught inside the space.

2. ACOUSTIC PERFORMANCE

a) Reverberation

- We consider the Seating Space of the café to do acoustic calculations.
- MATERIALS:
  - Walls, Floor - Hard Wearing, Exposed Concrete (course)
  - Ceiling - Exposed Concrete covered with sprayed cellulose fiber (25mm) on timber lath
  - Glazing - Glass (1/4" plate, large pane)
  - Seating - fabric-upholstered, empty
- We use the Sabine Formula in order to calculate reverberation time:

$$T_{60} = \frac{0.16\,V}{A}$$

T_{60} → Reverberation Time

V → Volume of Room (m^3)

A → Total Absorption of Room Surface (m^2sabins) $=\Sigma$(surface area x absorption coefficient)

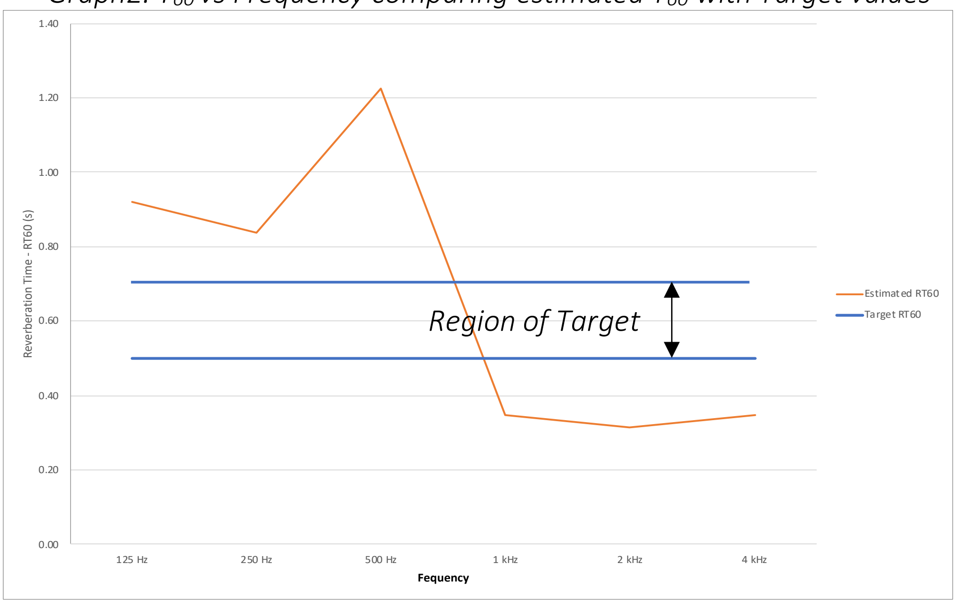
- Since different materials absorb sound differently at different frequencies, T_{60} is calculated over a range of 6 different frequencies.[B]

Table 6. T_{60} for varying frequencies

Frequency (Hz)	125	250	500	1000	2000	4000	Avg. T_{60} (s)
Reverberation Time T_{60} (s)	0.92	0.84	1.22	0.35	0.32	0.35	0.67

- Recommended T_{60} values of the café lie between 0.5-0.7 [2]. The average value is within this limit.
- However, we notice it exceeds the recommendation at lower frequencies (125-500 Hz)and precedes recommendation at higher frequencies (1000-4000 Hz).
- SHORTCOMINGS:
  - For simplification, the doors have not been considered while calculating T_{60} so the values calculated are not completely accurate.
  - The calculation for seating has only been done for an empty café and so these values may change as the café's occupancy changes (people occupy seat area).

Graph2. T_{60} vs Frequency comparing estimated T_{60} with Target values



b) Sound Insulation

- The façade closest to the road is the North Wall of the Seating Space, 40 m from the road.
- MATERIALS USED:
  - Windows - Double Glazed 4/150/4 with absorbent reveal
  - Doors - Acoustic door, double heavy sheet steel skin, absorbent in airspace, acoustic metal doorset and double seals in heavy steel frame
  - Wall - 200mm dense concrete (2300 kg/m3)
  - Gap – Of total area 0.01 m^2
- Sound levels in the room associated with the source as the road (40 m away) is calculated using [C]

$$L_p(r) = L_p(s) - R_{comp} - 10 \log \left(\frac{0.16\ V}{T_{60}\ S}\right)$$

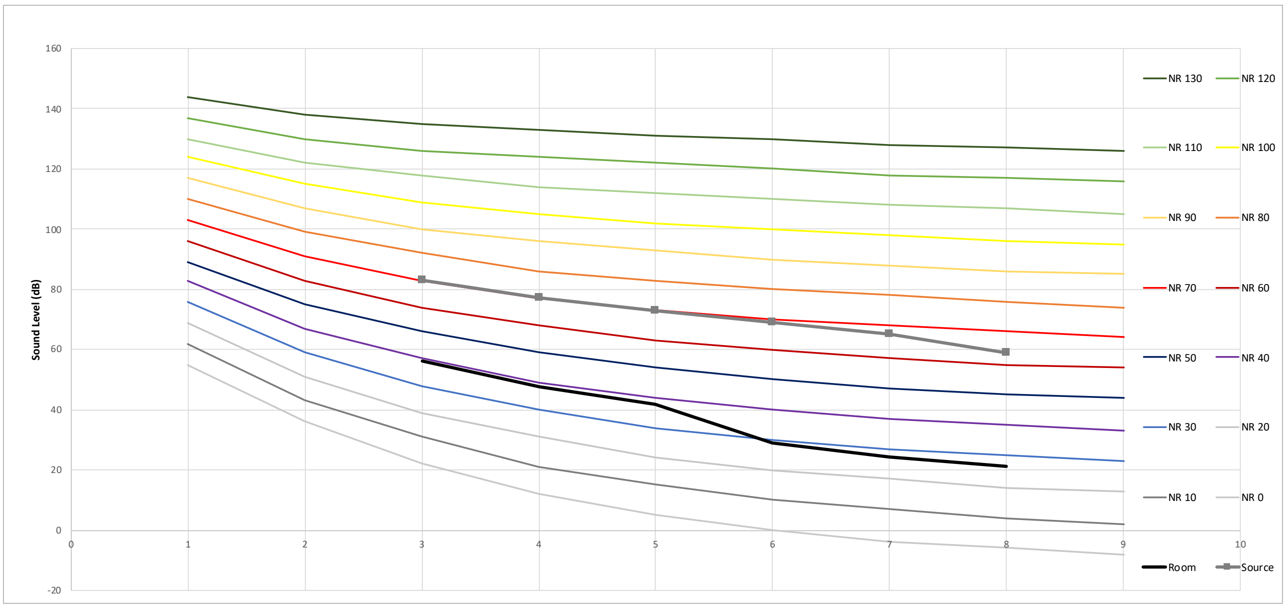
where
$L_p(r)$ = Sound level in room [dB]
$L_p(s)$ = Sound level from source (road) [dB]
R_{comp} = Composite Sound Reduction Index [dB]
V = Volume of Room [m^3]
T_{60} = Reverberation Time [s]
S = Surface Area of all components of the wall [m^2]

Table 7. $L_p(r)$ for varying frequencies

Frequency (Hz)	125	250	500	1000	2000	4000	Avg. $L_p(r)$ (dB)
$L_p(r)$ (dB)	56.06	47.73	41.64	28.81	24.17	21.18	36.6

- These values of $L_p(r)$ are used to plot the source and resulting room sound levels on the noise rating curve template to determine NR and compare to relevant guidelines.

Graph 3. Source and Resulting Room Sound Levels on noise rating curve template



- LIMITATIONS:
    - The Area of the Stack Chimney on the roof has not been taken into account which will result in subtle inaccuracies in calculated data.
    - The openings for cross ventilation on the façade have also not been taken into account while calculating Sound Levels so the values are not completely accurate.
    - The volume of the space increases when the stack ventilator is in operation. This change in volume has not been acknowledged in calculating T_{60} or Sound levels.
    - The values for T_{60} and $L_p(r)$ were in the desirable range for frequencies 1000-4000 Hz but were higher than suitable values for frequencies 125-500 Hz

c) Consideration of Further Noise

- Noise from human interaction within the café which may include
    - Customer conversation
    - Placing an order
    - Service related sounds
    - Movement of furniture
    - Sound of cutlery
- The seating area shares a wall with the kitchen which is a source of noise mainly due to the nature of its operation.
- The sound of drainage, flushing etc. may also be audible from the toilets.
- The sensors installed to operate the ventilation system may also potentially produce some sound in opening/closing the windows and the stack chimney.
- Here, only the sound through the north façade has been incorporated. Hence this does not account for the sound of traffic and/or external environment through other façades.
- The café is located by the beach and hence positive sounds like the sound of the ocean may also be heard in the café.
- Lastly, many imperfections in the building like gaps between wall and window, that may have arisen due to construction defects may also allow unwanted sounds to seep in.

3. DAYLIGHTING

a) Sun Path Diagrams and Hours of direct sunlight

- The café has windows on the North, West and South façades.
- Shading is added to the West and South façades of the café so that the mid height of the windows do not receive any direct sunlight during July and August and avoid summer overheating
- There is no shading on the North façade as it does not receive any direct sunlight.
- The South façade has 2 identical windows of 1.55 m x 1.5 m. We calculate the shading angle for a shade over lagging by 1.5 m and the vertical window recesses.
- The West façade has one window 2 m x 1.5 m and another window 2 m x 5.2 m. To simplify calculations we only consider the window with the larger area and calculate the same.

Figure 5. South Wall Shading angle for overlagging (top) and vertical window recesses (bottom)

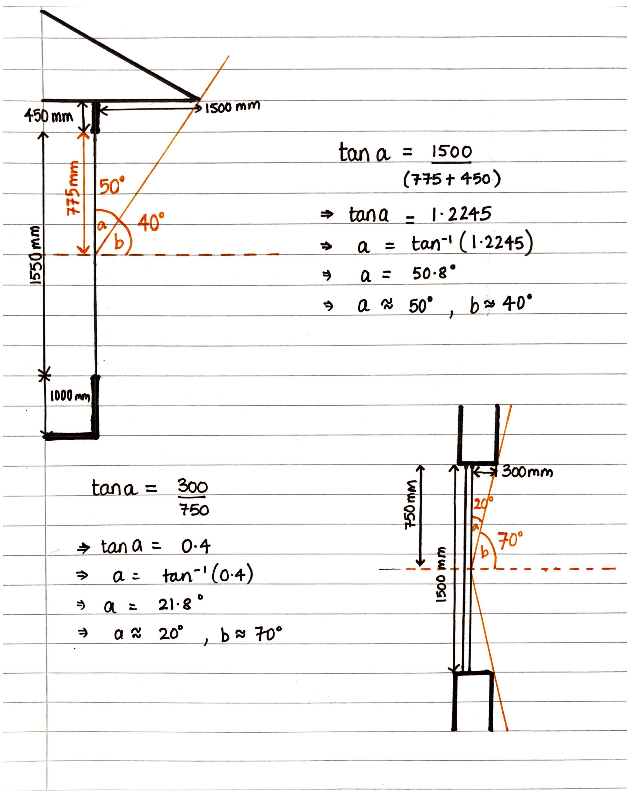
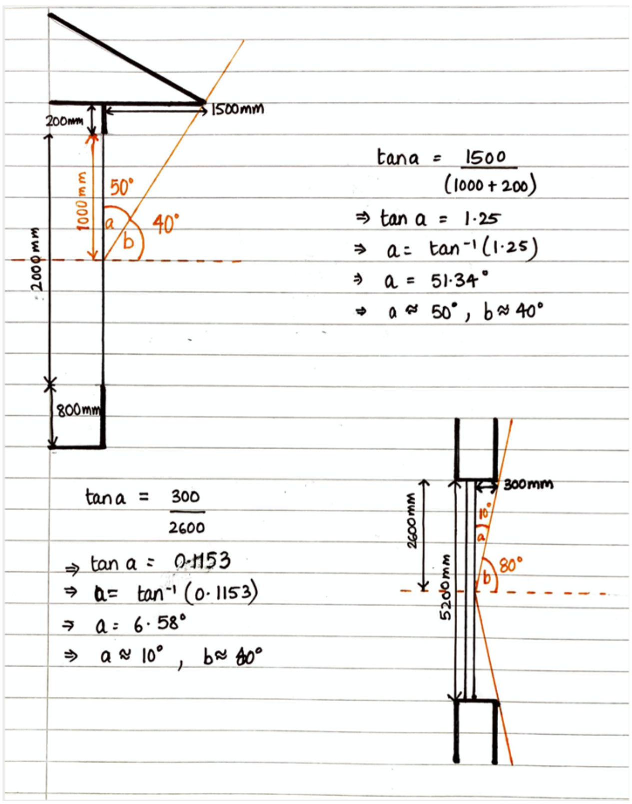


Figure 6. West Wall Shading angle for overlagging (top) and vertical window recesses (bottom)



- Using these values of the shading angles, sun path diagrams for the two respective facades are made.

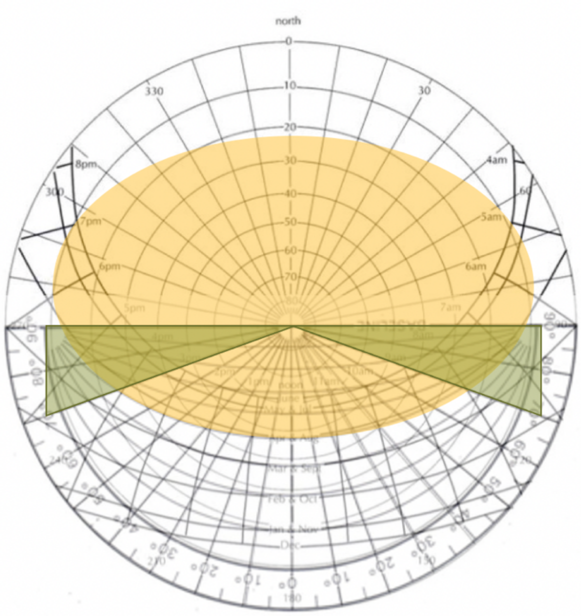


Figure 7. Sunlight Hours for South Façade

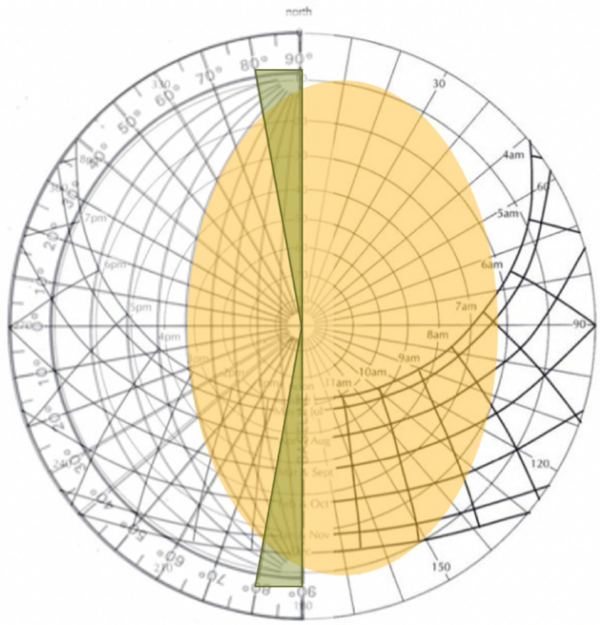


Figure 8. Sunlight Hours for West Façade

Table 8. Recording hours of direct sunlight on South and West Façade of Café

		Hours of Direct Sunlight		
Day	Sunrise	South Façade	West Façade	Sunset
June 21	4 am	-	-	8 pm
May/July 21	4 am	-	-	8 pm
April/August 21	5 am	-	-	7pm
March/September 21	6 am	7:30 am – 4:30 pm	2 pm – 4 pm	6 pm
February/October 21	7 am	7 am – 5 pm	2 pm – 5 pm	5 pm
January/November 21	8 am	8 am – 4 pm	1 pm – 6 pm	4 pm
December 21	8 am	10 am – 2 pm	12 pm – 7 pm	3:45 pm

- From the above table it can be analysed that the South and West Façade of the café do not receive any direct sunlight in the summer months (April – August).
- Considering the fact that the café timings are 9:00 – 23:00 , we can analyse that in the months from January to March and September to December, the café receives atleast 4 hours of direct sunlight daily.
- The effect of direct sunlight can be reduced by either glazing the glass of the windows or to use blinds/curtains on the windows. These help reduce glare and overheating.

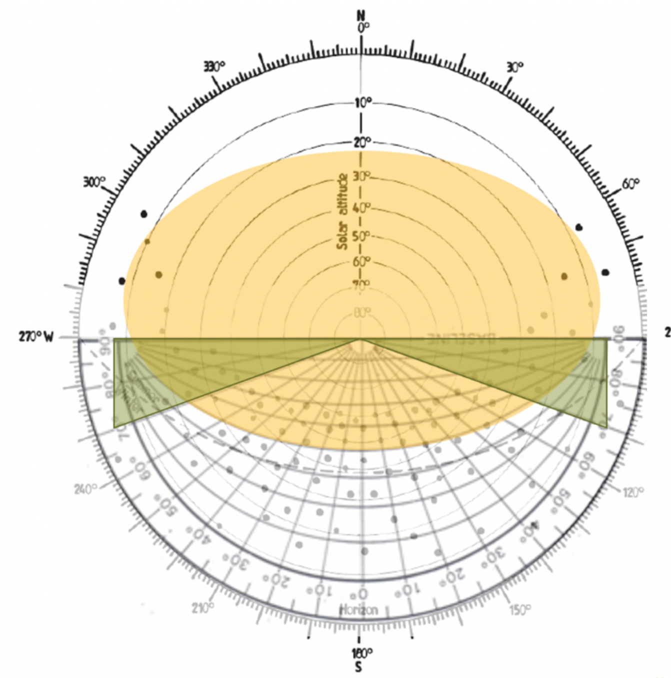


Figure 9. Annual Probable Sunlight Hours for South Façade

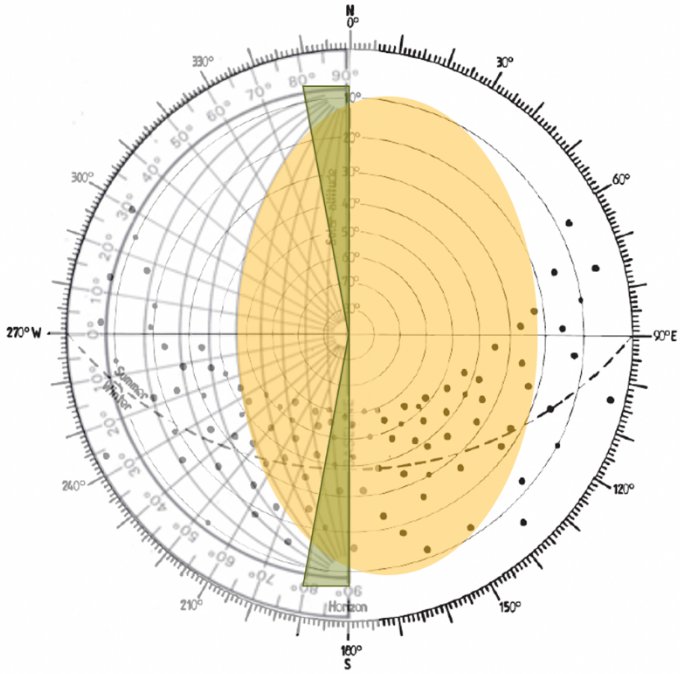


Figure 10. Annual Probable Sunlight Hours for West Façade

	% of Annual Probable Sunlight Hours		
	South Façade	West Façade	Total
Summer	11	21	32
Winter	26	9	35

Table 9. Annual Probable Sunlight Hours

b) Daylight Factor

- We use the daylighting tool in order to obtain the daylighting factors of the café [4].

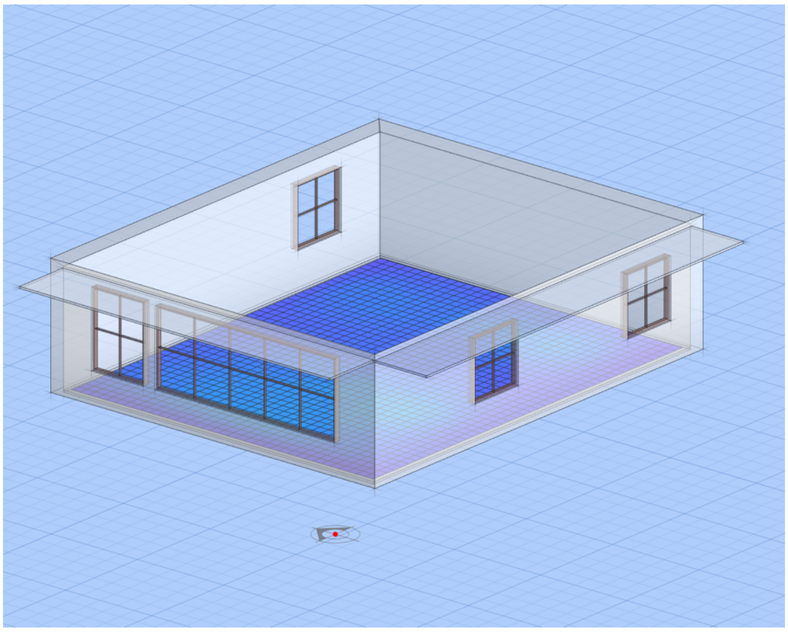


Figure 11. Representation of the café in the daylighting tool

- For a CIE Standard overcast sky we get

Average DF (%)	2.4
Maximum DF (%)	4.9

- For a CIE Standard clear sky, we calculate these values over three significant dates of the year, i.e., Summer Solstice, Winter Solstice and Equinox through three distinct operating times of the café.

Date	Time	Average DF (%)	Maximum DF (%)
21 June (Summer Solstice)	10:00	2.3	3.6
	15:00	3.2	8
	20:00	3.5	6.9
21 December (Winter Solstice)	10:00	2.8	4.8
	15:00	3.3	6
	20:00	0	0
21 March (Equinox)	10:00	2.7	5.1
	15:00	3.6	8.6
	20:00	0	0

Table 10. Average and Maximum daylight factors at varying points in the year and day

- It is noteworth that during winter solstice and equinox the DF is 0% at 20:00 indicating a need for artificial lighting.

c) Visual Comfort

- The North façade contains a steel skin door which is right in front of the direct sunlight coming from the South façade windows. In order to prevent this, a fabric coating on the door and as previously suggested, use of glazing or blinds/curtains on windows can help restore visual comfort.
- Since the café is open all days and evenings, after dark there is need for artificial lighting systems within the café in order to maintain visual comfort.
- Since the window sizes for the Kitchen and Toilets are not sufficient to provide sufficient light these spaces must completely rely on artificial lighting round the clock.
- As mentioned, windows facing direct sunlight should either be glazed or provided with blinds/curtains to be closed at the time when it is present.

4. CONCLUSION

This café was designed keeping in mind the basic principles of Ventilation, Acoustics and Daylighting.

Table 11. Café Specifications

	Length (m)	Width(m)	Height(m)
Seating Space	11	9	3
Kitchen	7	5	3
Toilet(s)	2	2	3

The ventilation strategy chosen was a combination of cross ventilation and stack ventilation through stack chimney, the latter to be used when there isn't sufficient wind to carry out the former. To accommodate this strategy the following sensor controlled single hung windows were used.

Table 12. Window Specifications

Window	Façade	Inflow/Outflow	Width [m]	Height [m]	Max. Openable Area [m^2]
1	South	Inflow	1.5	1.55	0.225
2	South	Inflow	1.5	1.55	0.225
3	West	Outflow	1.5	2	0.225
4	West	Closed	5.2	2	0
5	North	Outflow	1.5	1.55	0.225

In addition to these, a stack ventilating chimney was also installed in the geometric centre of the roof of the seating space

Dimension	Length [m]	Width [m]	Height [m]
Stack Chimney	3	0.3	3

This ventilation strategy eliminates individual drawbacks of cross and stack ventilation however, the actual efficiency of this strategy is not know as it depends heavily on the environmental conditions of the location which have not been extensively discussed.

The reverberation time (T_{60} = 0.67 s) for the café was obtained between the recommended values by strategic selection of materials with high absorption coefficients. Taking into account the sound insulation of the road-facing North façade the room sound levels calculated were above the required NR30 levels for lower frequencies but below for higher frequencies. The sound insulation was brought about by the use of double glazed windows, acoustic doors and dense concrete walls. Overall the acoustic strategy was successful for higher frequencies but insufficient for lower frequencies.

Finally, with the help of Sunpath diagrams, the south and west walls were shaded using a shade with a overhang of 1.5 m and the windows recessed by 300 mm. Also the hours of direct sunlight were calculated. Since they are all during the opening hours of the café the best solution to prevent glare and over-heating is glazing the windows. Alternatively blinds/curtains can also be provided.

APPENDIX

[A] CALCULATION OF OPENING SIZES USING CIBSE AM10 TOOL

Calculating appropriate ventilation rates for CO_2 levels to be below 1000 ppmv using the IAQ tab

Room volume (m3)	297.0
CO2 emission rate (l/hr.p)	20.0
Initial CO2 concentration (ppmv)	700.0

Condition set	Outside CO2 ppmv	No. of Occupants	Air change rate (hr-1)	Rate equiv. to 10l/s.p
1	450.0	0.0	1.000	0.000
2	450.0	2.0	1.800	0.242
3	450.0	10.0	2.300	1.212
4	450.0	15.0	2.700	1.818
5	450.0	26.0	3.600	3.152

Av. concn during occ. hours (ppmv)	**717.7**
Max concn during occ. hours (ppmv)	**936.3**
Max deviation from average	**30.5%**

Hour beginning	Condition set applying this hour	Concn at end of hour (ppmv)
0.00	1	542.0
1.00	1	483.8
2.00	1	462.4
3.00	1	454.6
4.00	1	451.7
5.00	1	450.6
6.00	1	450.2
7.00	1	450.1
8.00	1	450.0
9.00	2	512.5
10.00	3	719.7
11.00	3	740.5
12.00	4	818.5
13.00	5	933.1
14.00	5	936.3
15.00	5	936.3
16.00	2	592.8
17.00	2	536.1
18.00	3	722.1
19.00	3	740.7
20.00	3	742.6
21.00	3	742.8
22.00	2	560.8
23.00	2	530.8
24.00	1	479.7

Using ventilation rates for 0,10 and 26 people to calculate corresponding opening sizes using the isolated tab

for 26

Case 4 - Cross-flow ventilation by wind alone	
Required flowrate (m3/s)	0.397
Wind speed at building height (m/s)	3.0
Discharge coefficient	0.61
Wind pressure coefficients	
windward side	0.50
leeward side	-0.20
Required area	0.367

for 0

Case 4 - Cross-flow ventilation by wind alone	
Required flowrate (m3/s)	0.083
Wind speed at building height (m/s)	3.0
Discharge coefficient	0.61
Wind pressure coefficients	
windward side	0.50
leeward side	-0.20
Required area	0.076

for 10

Case 4 - Cross-flow ventilation by wind alone	
Required flowrate (m3/s)	0.190
Wind speed at building height (m/s)	3.0
Discharge coefficient	0.61
Wind pressure coefficients	
windward side	0.50
leeward side	-0.20
Required area	0.175

[B] CALCULATION OF REVERBERATION TIME

Room Dimensions		
Length	11	*m*
Width	9	*m*
Height	3	*m*
Volume	297	*m3*

Element	Area/ Quantity	Units	Material	Absorption Coefficient						Total Absorption of room surfaces (m2 Sabins)						
				125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	
North Wall	30.675	*m2*	Concrete block (coarse)	0.36	0.44	0.31	0.29	0.39	0.25	11.043	13.497	9.50925	8.89575	11.96325	7.66875	
South Wall	28.35	*m2*	Concrete block (coarse)	0.36	0.44	0.31	0.29	0.39	0.25	10.206	12.474	8.7885	8.2215	11.0565	7.0875	
West Wall	13.6	*m2*	Concrete block (coarse)	0.36	0.44	0.31	0.29	0.39	0.25	4.896	5.984	4.216	3.944	5.304	3.4	
East Wall	27	*m2*	Concrete block (coarse)	0.36	0.44	0.31	0.29	0.39	0.25	9.72	11.88	8.37	7.83	10.53	6.75	
Ceiling	99	*m2*	Sprayed cellulose fiber (25mm	0.15	0.11	0.04	1.03	1.05	1.03	14.85	10.89	3.96	101.97	103.95	101.97	
Floor	99	*m2*	Concrete (poured, rough finish	0.01	0.02	0.04	0.06	0.08	0.1	0.99	1.98	3.96	5.94	7.92	9.9	
Glazing	20.375	*m2*	Glass (1/4" plate, large pane)	0.18	0.06	0.04	0.03	0.02	0.02	3.6675	1.2225	0.815	0.61125	0.4075	0.4075	
Seating	9.6	*m2*	Seats (fabric-upholsterd, empt	0.49	0.66	0.8	0.88	0.82	0.7	4.704	6.336	7.68	8.448	7.872	6.72	
Other 2			Brick (natural)	0.03	0.03	0.03	0.04	0.05	0.07	0	0	0	0	0	0	
Other 3			Brick (natural)	0.03	0.03	0.03	0.04	0.05	0.07	0	0	0	0	0	0	
Other 4			Brick (natural)	0.03	0.03	0.03	0.04	0.05	0.07	0	0	0	0	0	0	
Other 5			Brick (natural)	0.03	0.03	0.03	0.04	0.05	0.07	0	0	0	0	0	0	
Other 6			Brick (natural)	0.03	0.03	0.03	0.04	0.05	0.07	0	0	0	0	0	0	
									Total	51.705	56.705	38.80375	136.80125	150.72375	136.77625	**Average**
									RT60	0.92	0.84	1.22	0.35	0.32	0.35	**0.67**
									Target	0.5	0.5	0.5	0.5	0.5	0.5	0.50

[C] CALCULATION OF $L_p(r)$

Obtain values of Sound Reduction Indices (R_i) and use these values to calculate Transmission Indices (T_i)

$$T_i = 10^{-\left(\frac{R_i}{10}\right)}$$

Transmission Index

Concrete	Frequency	125	250	500	1000	2000	4000
	Sound Reduct	42	46	50	57	60	65
	Transmission	6.30957E-05	2.51189E-05	0.00001	1.99526E-06	0.000001	3.16228E-07
Door	Frequency	125	250	500	1000	2000	4000
	Sound Reduct	35	39	44	49	54	57
	Transmission	0.000316228	0.000125893	3.98107E-05	1.25893E-05	3.98107E-06	1.99526E-06
Windows	Frequency	125	250	500	1000	2000	4000
	Sound Reduct	38	35	41	54	48	38
	Transmission	0.000158489	0.000316228	7.94328E-05	3.98107E-06	1.58489E-05	0.000158489
Gap	Frequency	125	250	500	1000	2000	4000
	Sound Reduct	0	0	0	0	0	0
	Transmission	1	1	1	1	1	1

Calculate Composite Transmission Indices (T_{comp}) and subsequently Composite Sound Reduction Indices (R_{comp})

$$T_{comp} = (T_1S_1 + T_2S_2 + ...)/(S_1 + S_2 + ...)$$
$$R_{comp} = 10\log_{10}(1/T_{comp})$$

Composite Transmission Index

Frequency	125	250	500	1000	2000	4000
Wall	6.30957E-05	2.51189E-05	0.00001	1.99526E-06	0.000001	3.16228E-07
Door	0.000316228	0.000125893	3.98107E-05	1.25893E-05	3.98107E-06	1.99526E-06
Window	0.000158489	0.000316228	7.94328E-05	3.98107E-06	1.58489E-05	0.000158489
Gap	0.999963507	0.999927189	0.99998171	0.999999083	0.999996351	0.999963507
T_comp	0.003165033	0.002030873	0.000860097	0.000396759	0.000377034	0.000684818
R_comp	24.99621771	26.92317208	30.65452613	34.01473606	34.23618992	31.6442504

Calculate $L_p(r)$ using the formula

$$L_p(r) = L_p(s) - R_{comp} - 10 \log \left(\frac{0.16\ V}{T_{60}\ S}\right)$$

R_comp	24.99621771	26.92317208	30.65452613	34.01473606	34.23618992	31.6442504
T_60	0.919060052	0.838021339	1.224623909	0.347365247	0.31527878	0.347428739
Lp(s)	83	77	73	69	65	59
Lp(r)	56.05491211	47.72706962	41.64319213	28.81081853	24.16844842	21.18209792

Plot values of $L_p(r)$ and $L_p(s)$ on the noise rating curve template

Maximum Sound Pressure Level *(dB)*									
Noise Rating - NR -	**Octave band mid-frequency *(Hz)***								
Curve	**31.5 Hz**	**62.5 Hz**	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
NR 0	55	36	22	12	5	0	-4	-6	-8
NR 10	62	43	31	21	15	10	7	4	2
NR 20	69	51	39	31	24	20	17	14	13
NR 30	76	59	48	40	34	30	27	25	23
NR 40	83	67	57	49	44	40	37	35	33
NR 50	89	75	66	59	54	50	47	45	44
NR 60	96	83	74	68	63	60	57	55	54
NR 70	103	91	83	77	73	70	68	66	64
NR 80	110	99	92	86	83	80	78	76	74
NR 90	117	107	100	96	93	90	88	86	85
NR 100	124	115	109	105	102	100	98	96	95
NR 110	130	122	118	114	112	110	108	107	105
NR 120	137	130	126	124	122	120	118	117	116
NR 130	144	138	135	133	131	130	128	127	126
Source			**83**	**77**	**73**	**69**	**65**	**59**	
Room			56.05491	47.72707	41.64319	28.81082	24.16845	21.1821	

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