

Energy saving of building based on natural ventilation

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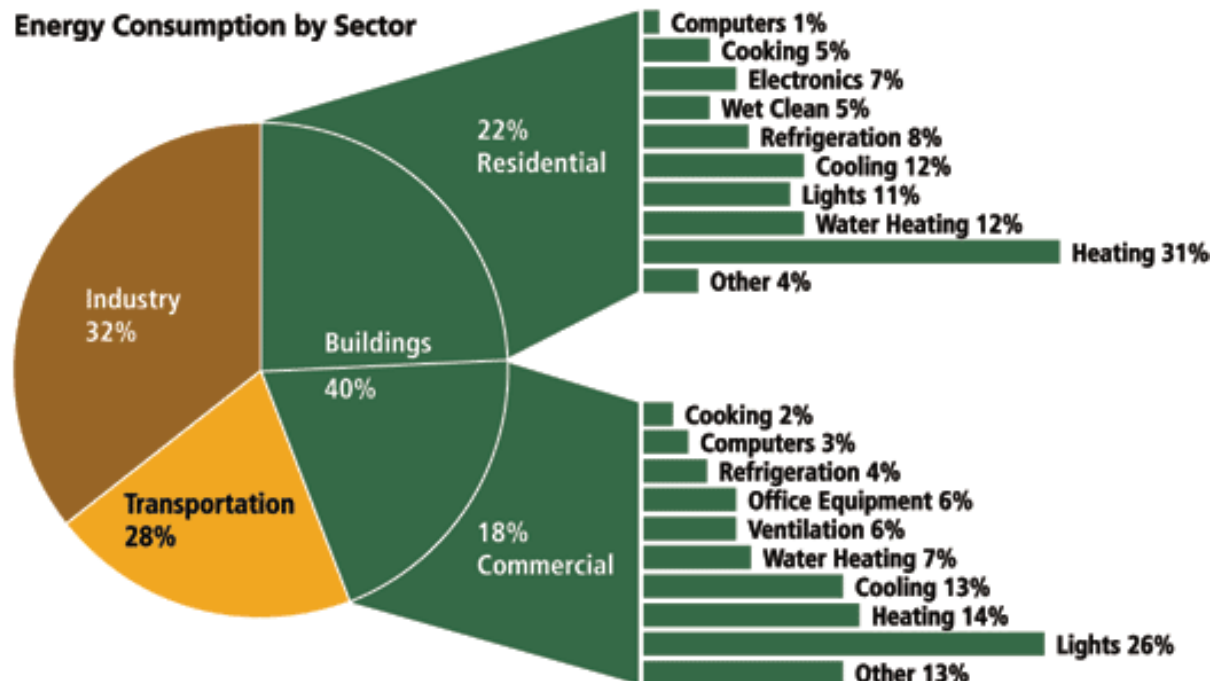


MAIN CONTENTS

- **Introduction**
- Fundamentals of solar chimney
- Application and performance
- Wall and roof solar chimney
- Real applications
- Solar chimney and fire safety
- Conclusions

INTRODUCTION

- Built environment is one of the largest consumers of energy in Australia, while space conditioning comprises **41% and 39% of all energy use** in the residential and commercial sectors.



Global energy consumption

INTRODUCTION

- Australian Sustainable Built Environment Council (ASBEC) suggests that improving energy efficiency in building can offer a **total \$26.7 billion saving** for residential and non-residential building between now and 2050.
- Melbourne City Council has initiated a **1,200 Building Program** for the related energy retrofitting.



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FUNDAMENTALS OF SOLAR CHIMNEY

- Solar chimney is a reliable renewable energy system to enhance the natural ventilation of buildings.

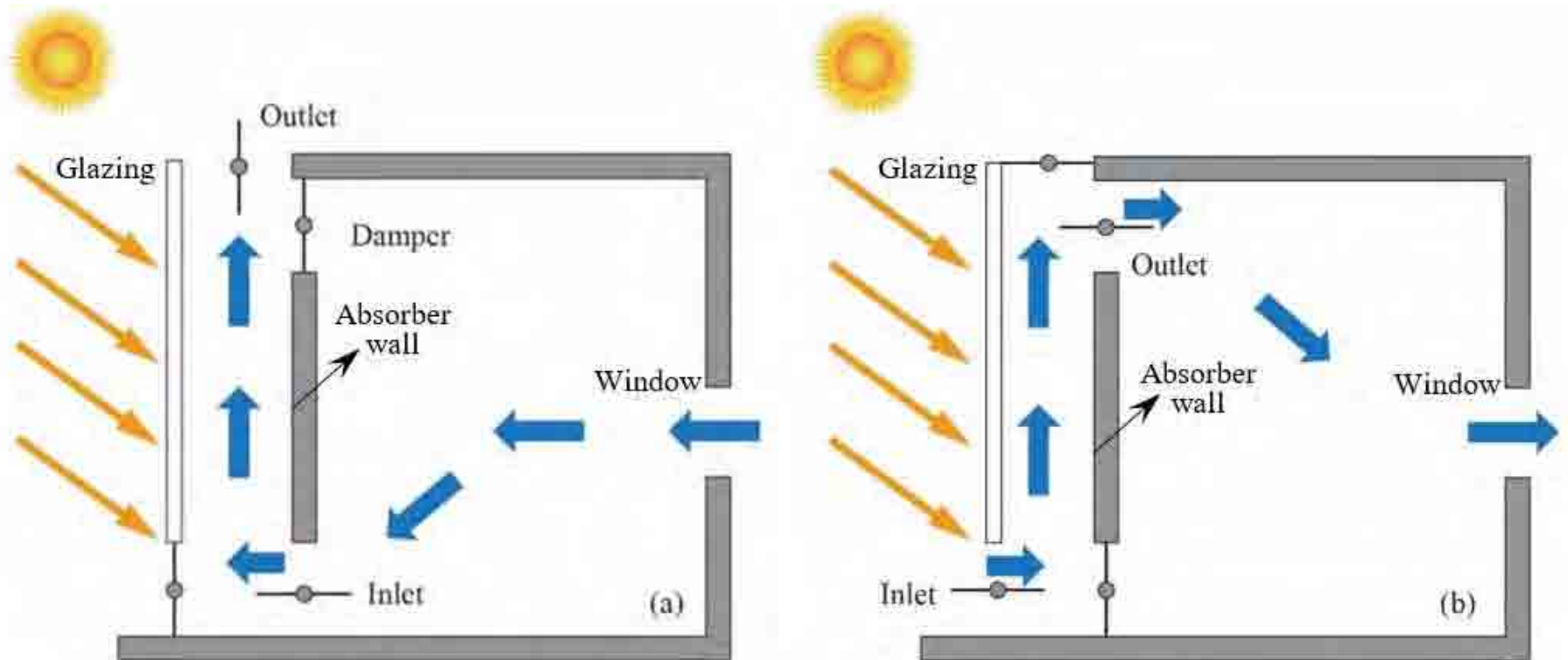
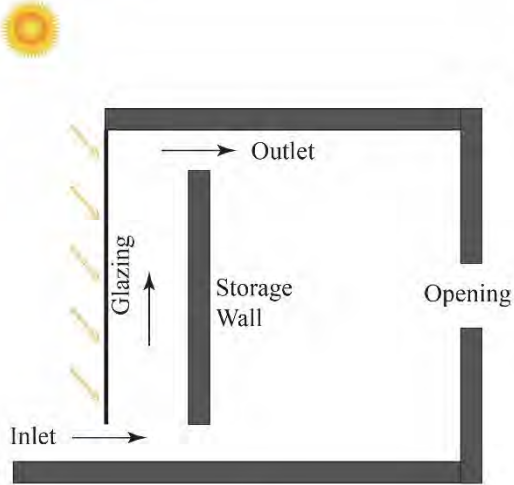
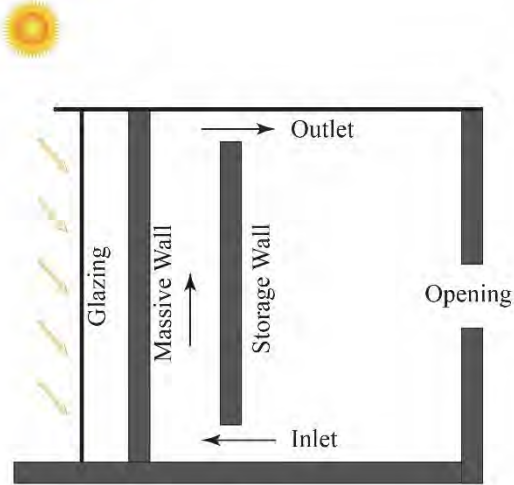


Figure 1 Typical wall solar chimney under: (a) cooling mode; and (b) heating mode

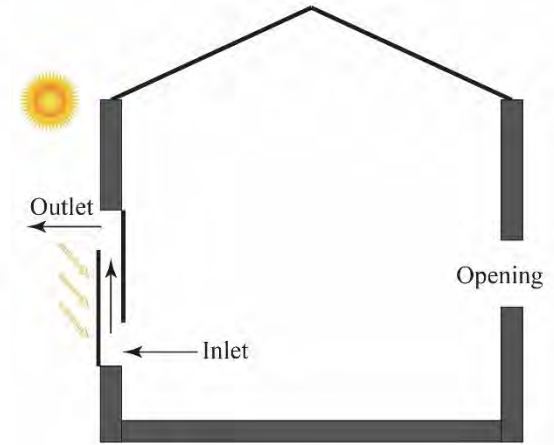
WHAT ARE THE TYPES?



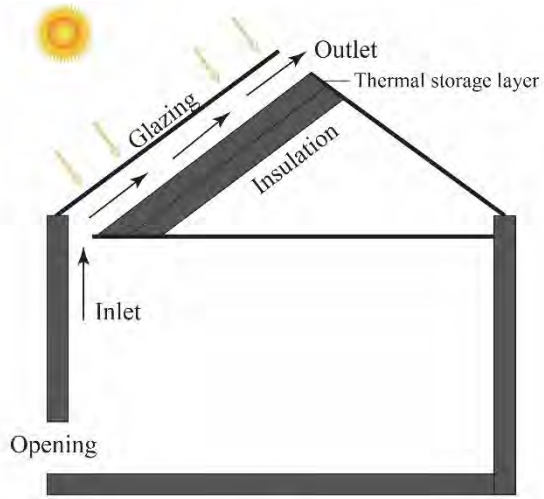
(a)



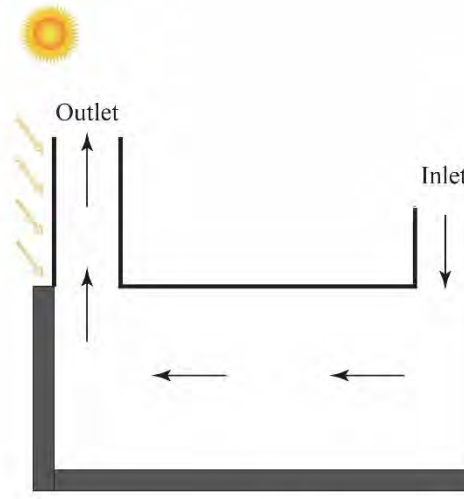
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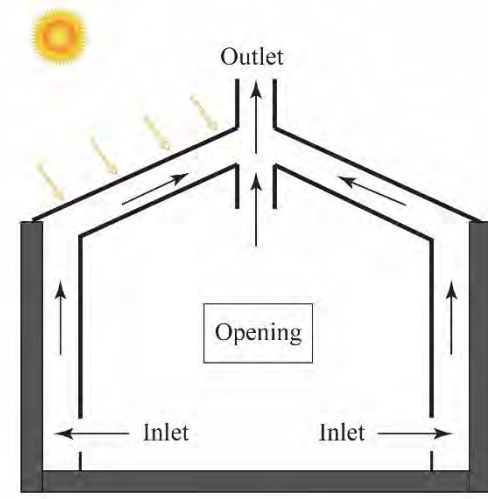
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(d)

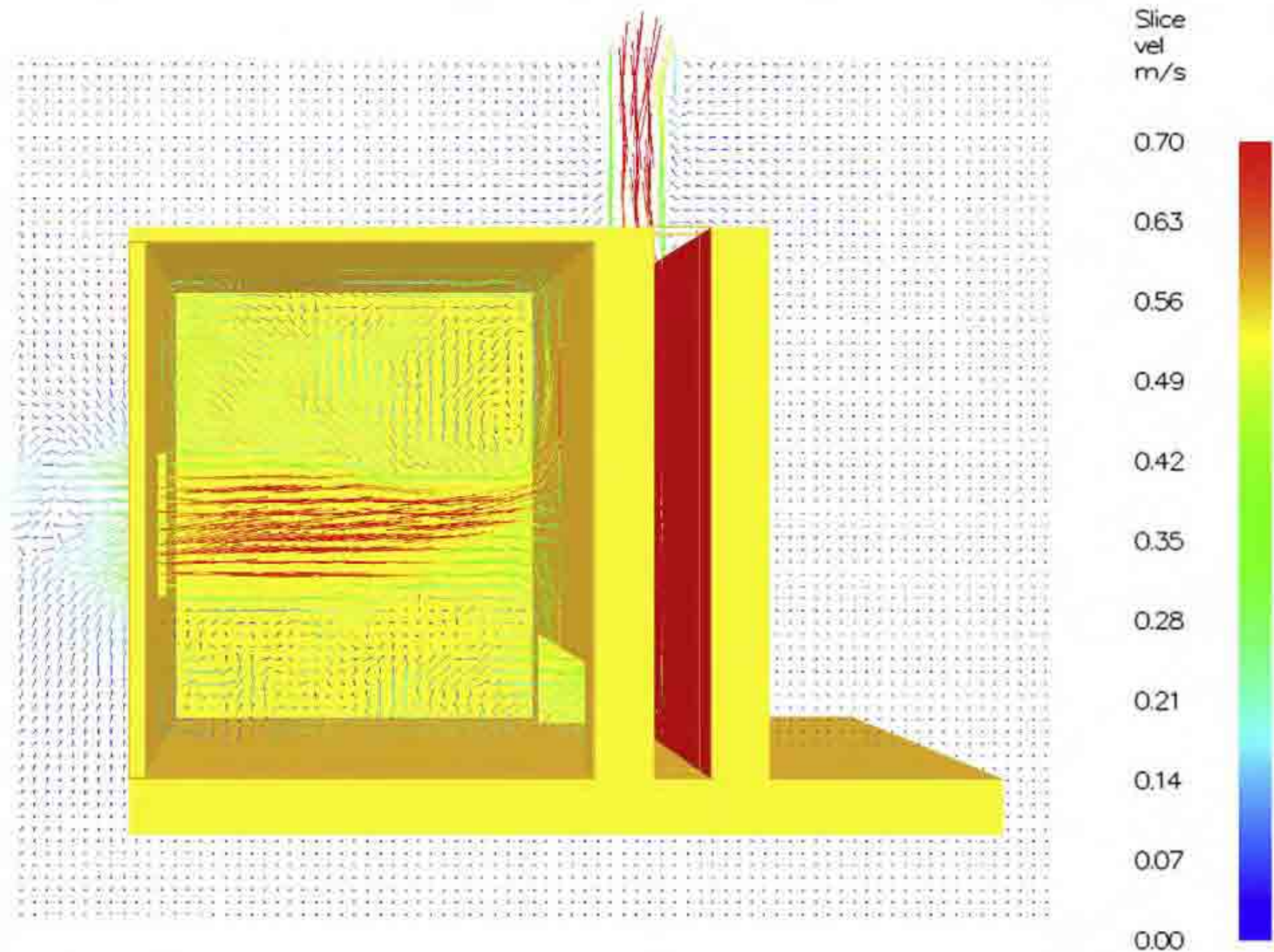


(e)



(f)

HOW SOLAR CHIMNEY WORKS

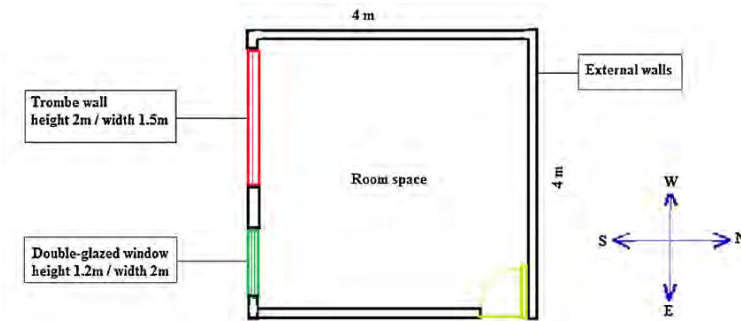
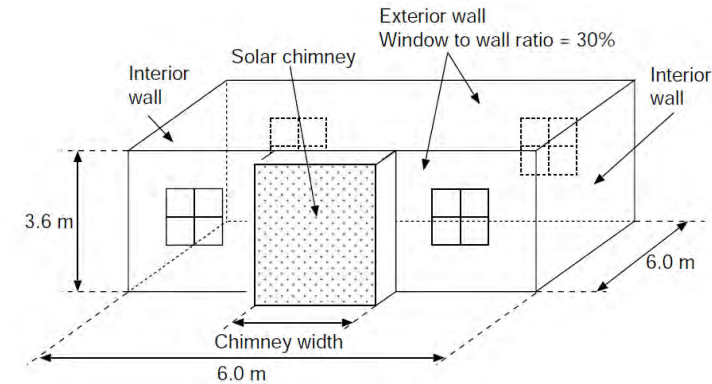


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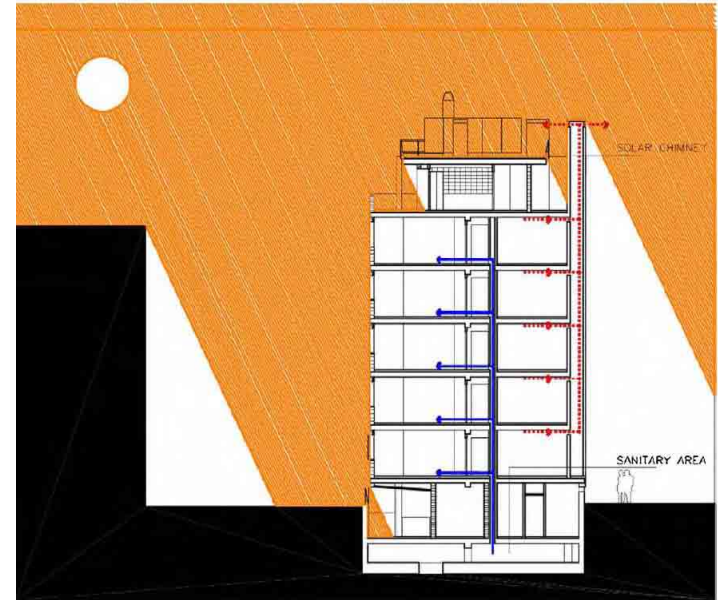
CASE STUDIES IN ASIA AND AFRICA

- Miyazaki et al. obtained that 1 m wide solar chimney can reduce about 90% fan usage in January and February, and **overall 50% annual saving** in Japan;
- Abbassi et al. indicated that 6 m² solar chimney can **reduce the 97% heating loading** of a 16 m² room, almost zero heating loading in Tunis.



CASE STUDIES IN EUROPE

- Jaber et al. indicated that the overall **annual energy heating load can be reduced by 32.1%** if 37% of the wall of the living room can install the solar chimney in Germany;
- Macias et al. in Spain concluded through data analysis that the annual energy saving of a building can be **more than 50%** if it is installed a solar chimney.



CASE STUDIES IN MELBOURNE

- Australian Conservation Foundation built a office building with solar chimney, called **60L Green Building**;
- Three solar chimneys were installed at the top of the building;
- Comparing to a regular building, the installation of solar chimney can **reduce 23% energy consumption** during the whole year.



APPLICATIONS AND PERFORMANCE



Solar chimney in Changzhou, China



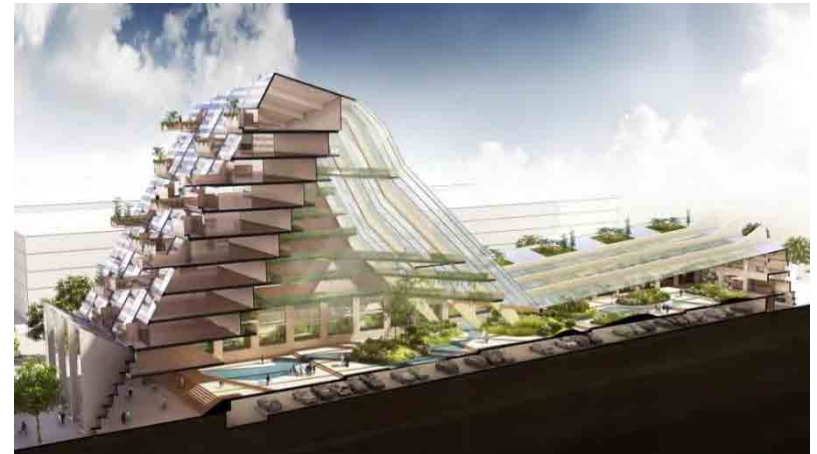
Fregusson solar house in Hobart
built in 1978



Solar thermal façade in Paris

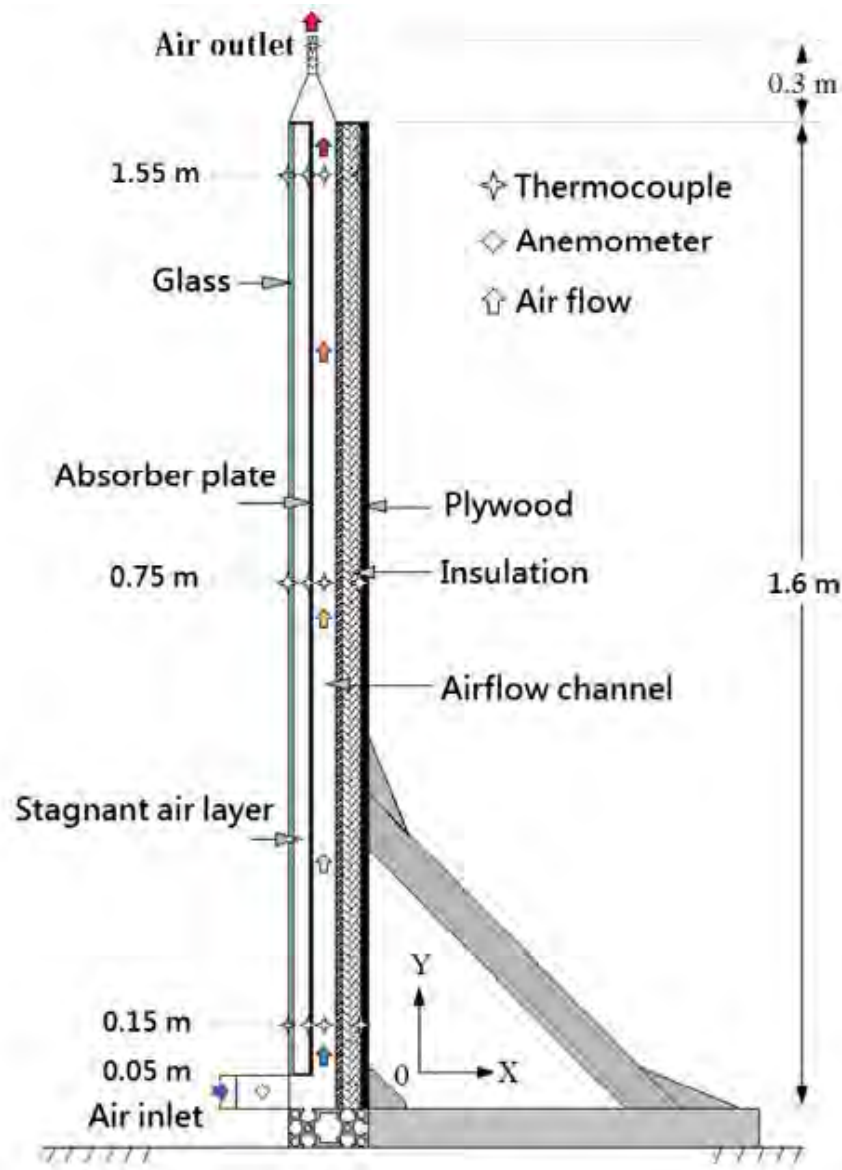


National Renewable Energy Laboratory (NREL)



De Kameel van Nord in Netherlands

WHAT ASPECTS HAVE BEEN EXPLORED?



Most of the previous research have been taken on optimization design :

- **Configuration** (height, cavity gap, inlet and outlet areas, height/gap ratio);
- **Installation condition** (inclination angle, opening and solar collector);
- **Material usage** (glazing, solar absorber, and thermal insulation);
- **Environment** (Climate, solar radiation, external wind)

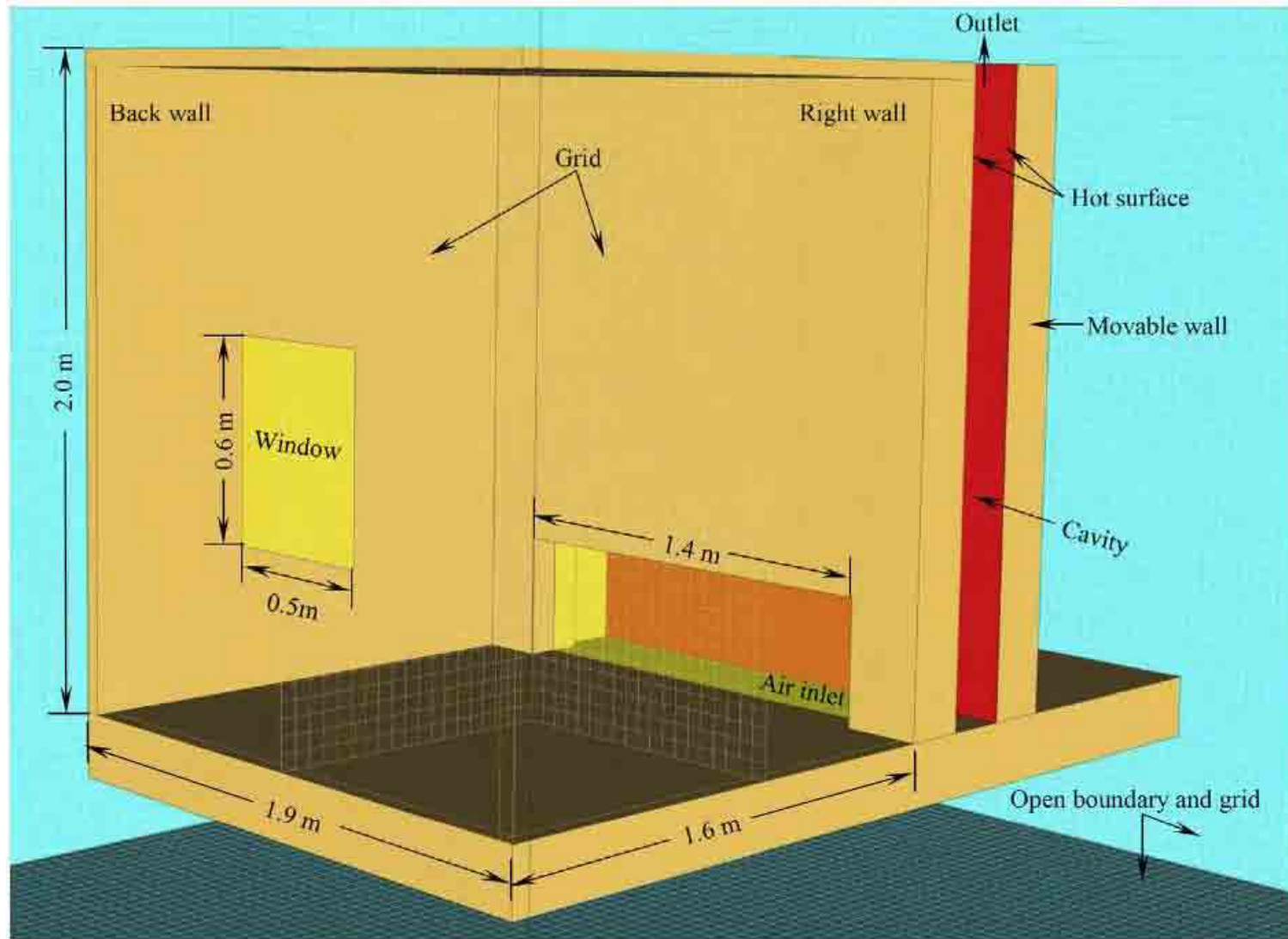
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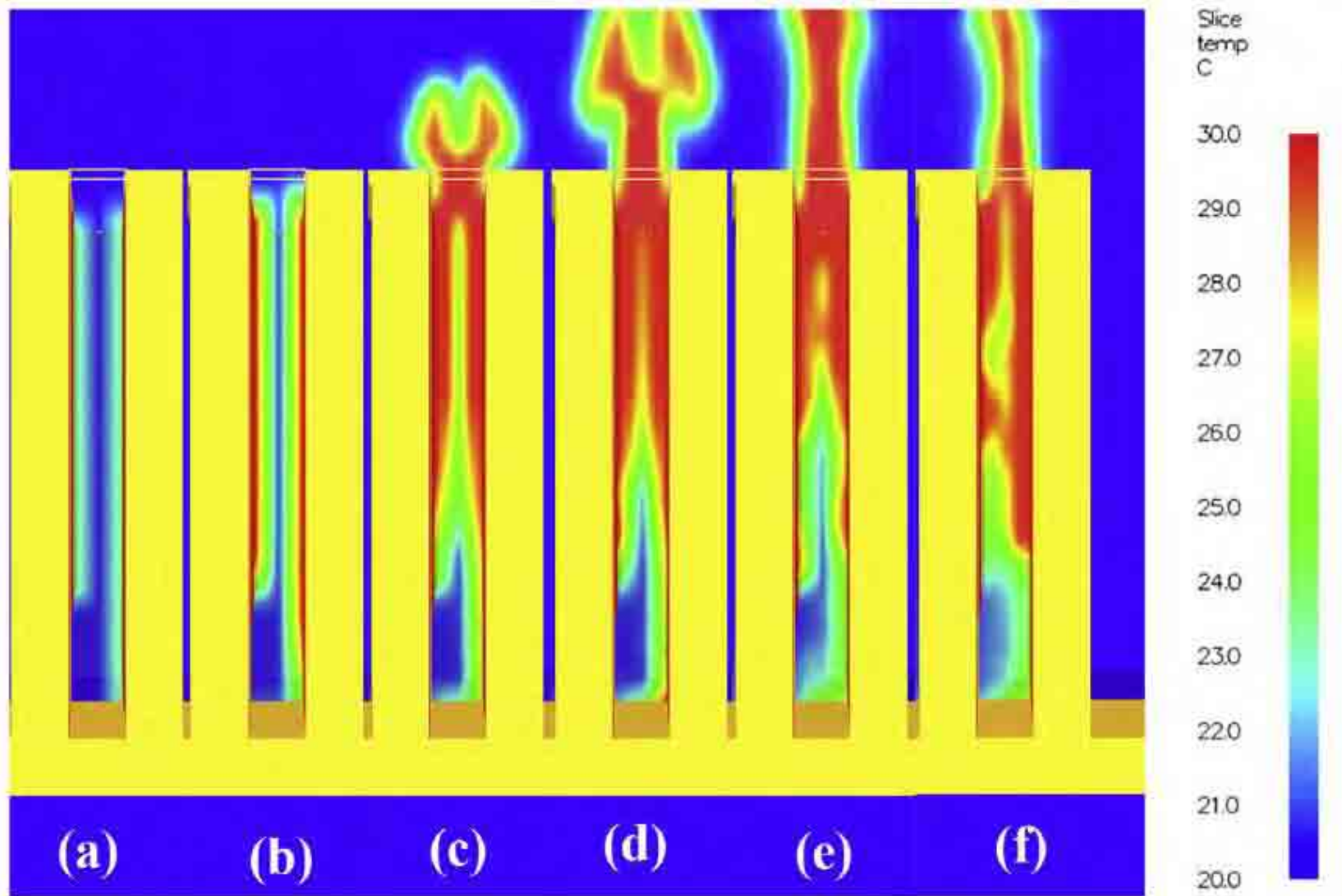
RESEARCH GAPS

- Almost all the previous studies have been focusing on **solo chimney cavity** without considering the connecting room, which produce errors in the real performance evaluation under various climatic conditions;
- Optimization design should be done to transition from **single season to both winter and summer usages**;
- Expansion of the **extra function** to further reduce the cost of the solar chimney to promote its viability under various locations.

WALL SOLAR CHIMNEY



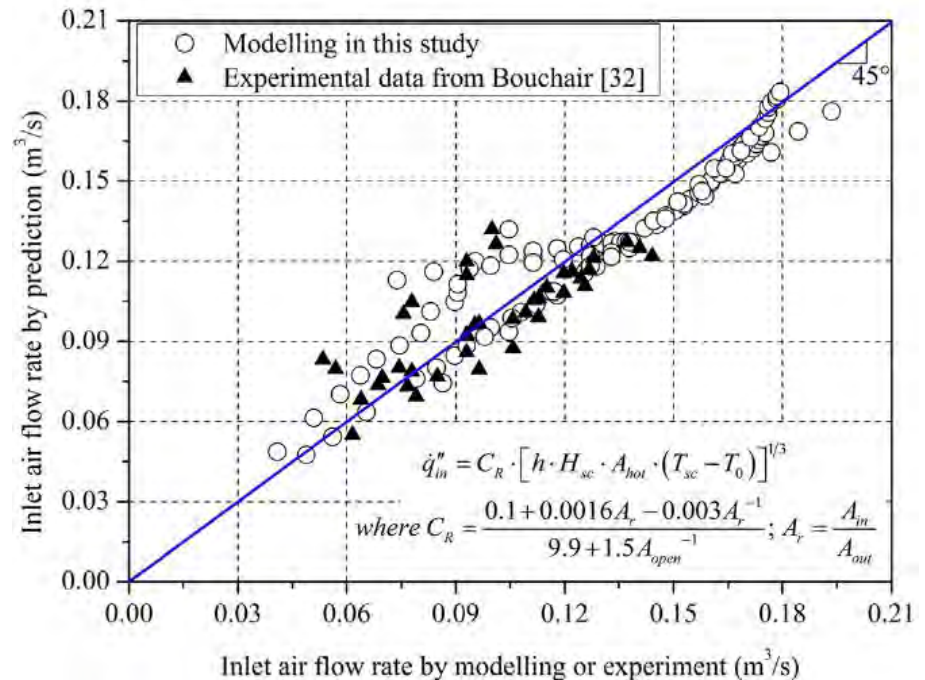
TEMPERATURE ALONG THE TIME



The temperature in the 0.2 m wide cavity with a hot surface temperature of 60 C along the time: (a) 1 s; (b) 2 s; (c) 4 s; (d) 5 s; (e) 20 s; and (f) 50 s.

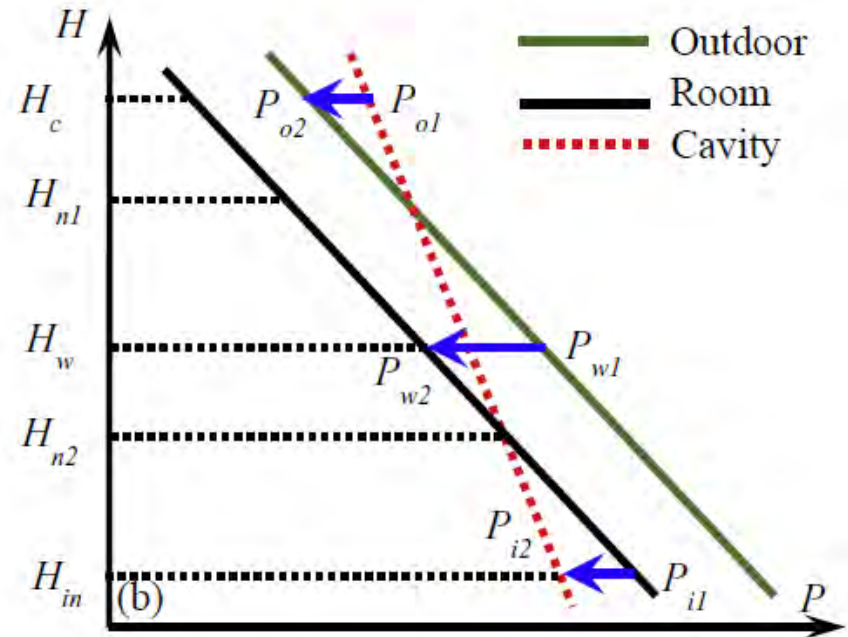
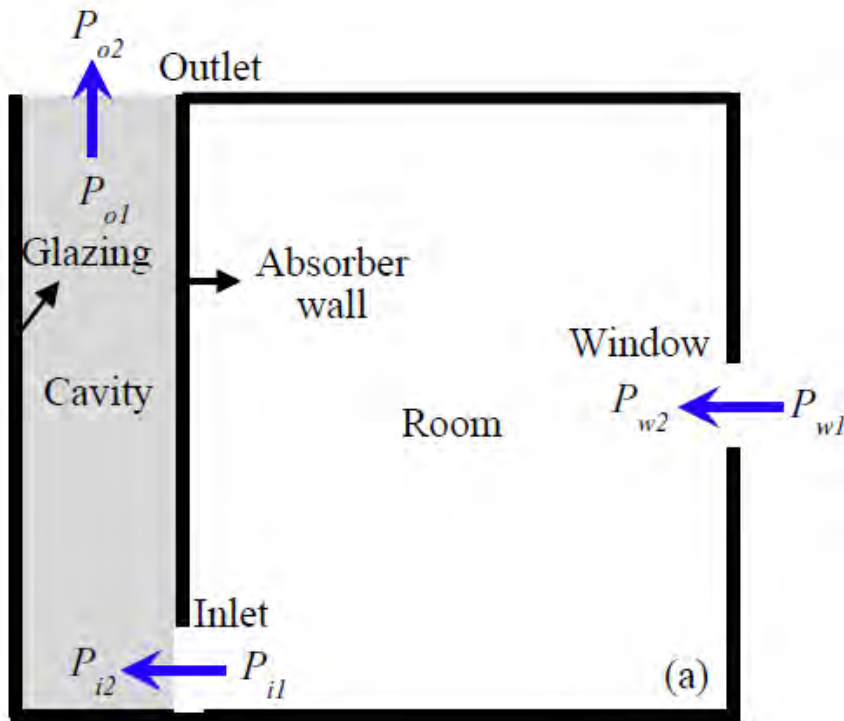
WALL SOLAR CHIMNEY

- It is observed that the **room size (e.g., length, width and height) has limited effect** on the air inlet flow.
- The air inlet flow rate **risers with a bigger opening**, but the flow seems to approach a maximum value.



$$\dot{q}_{in}'' = C_R \cdot [h \cdot H_{sc} \cdot A_{hot} \cdot (T_{sc} - T_0)]^{1/3}, \text{ where } C_R = \frac{0.1 + 0.0016A_r - 0.003A_r^{-1}}{9.9 + 1.5A_{open}^{-1}}; A_r = \frac{A_{in}}{A_{out}}$$

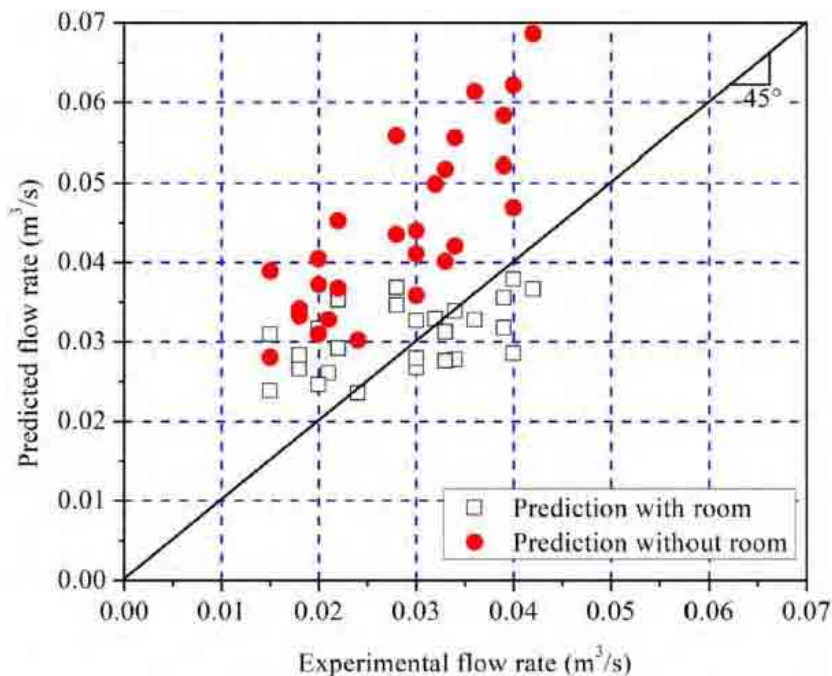
WALL SOLAR CHIMNEY



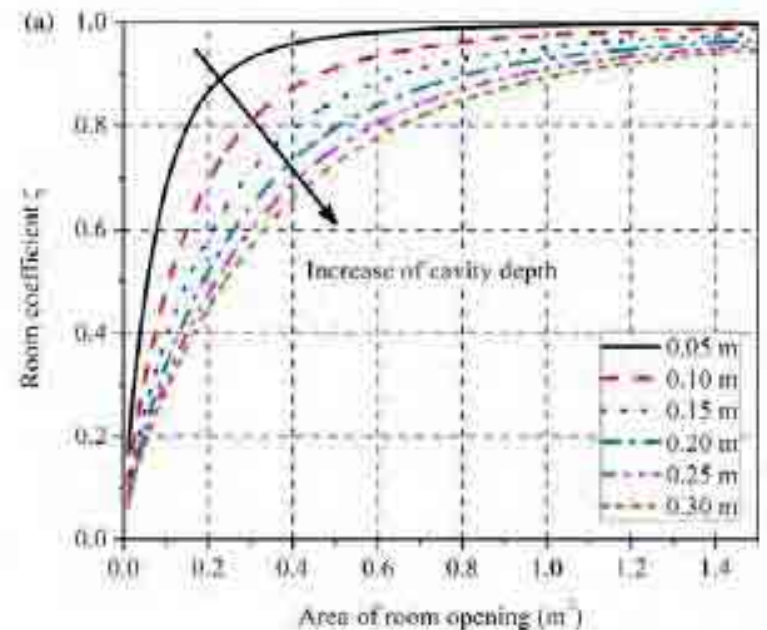
Solar chimney configuration and the static pressure along the height

ROOM COEFFICIENT

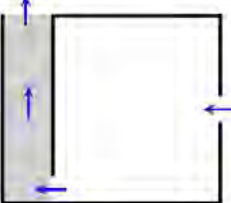
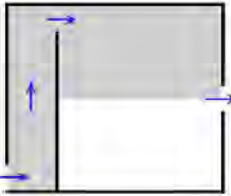
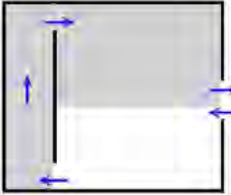
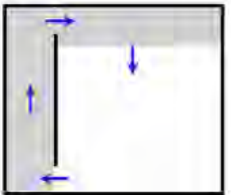
- A room coefficient was proposed to address the influences of room configuration on solar chimney performance.



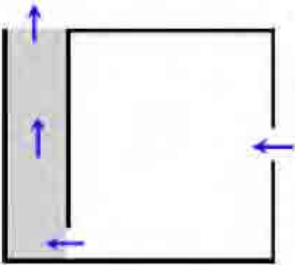
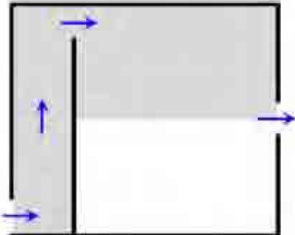
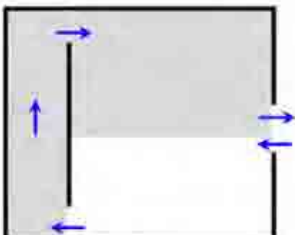
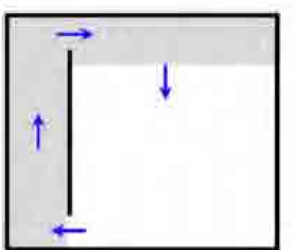
$$A_w > \left[\left(\zeta^{-3} - 1 \right) (A_i + A_o) \right]^{-0.5}$$



WALL SOLAR CHIMNEY

Category	Schematic	Theoretical models	Note
Cooling			$A^* = \frac{2A_i^2 A_o^2 A_w^2}{A_o^2 A_w^2 + A_i^2 A_w^2 + A_i^2 A_o^2}$ $H = H_o$
Fresh-air heating through cavity		$V_o = (C_d A^*)^{2/3} (BH)^{1/3}$ $T_c = \left(\frac{T_0}{gH} \right)^{1/3} \left(\frac{E}{\rho_0 C_p C_d A^*} \right)^{2/3} + T_0$	$A^* = \frac{2A_i^2 A_o^2 A_w^2}{A_o^2 A_w^2 + A_i^2 A_w^2 + A_i^2 A_o^2}$ $H = H_w$
Fresh-air heating through room		$l_{ste} = \frac{A_r (H_c - H_w)}{(C_d A^*)^{2/3} (BH)^{1/3}}$	$A^* = \frac{2A_i^2 A_o^2 A_w^2}{A_o^2 A_w^2 + A_i^2 A_w^2 + 8A_i^2 A_o^2}$ $H = H_w + 0.25h_{s,w}$ $H_{hot} = \max \left[H_c - \frac{t(C_d A^*)^{2/3} (BH)^{1/3}}{A_r}, H_w \right]$
Sealed heating		$V_o = (C_d A^*)^{2/3} (BH)^{1/3}$ $T_c = \left(\frac{\eta \mu_a Q_{sol}}{\sigma} + T_0^4 \right)^{1/4}$ $l_{ste} = \frac{3A_r H_c^{2/3}}{2B^{1/3} (C_d A^*)^{2/3}}$	$A^* = \frac{2A_i^2 A_o^2}{A_i^2 + A_o^2}$ $H = H_{Hot} = \max \left\{ H_c^{2/3} - \frac{2tB^{1/3} (C_d A^*)^{2/3}}{3A_r} \right\}^{3/2}, 0 \right\}$

APPLICABILITY OF DIFFERENT TYPES

Type	Schematic	Advantages	Disadvantages	Applicability
Fresh-air cooling		<ul style="list-style-type: none"> • Fresh-air exchange to keep the air quality of building; • Take away the internal heat load through the natural ventilation; 	<ul style="list-style-type: none"> ✓ Under very high-temperature weather condition, it may need to be used with other mechanical cooling. 	Regularly occupied buildings under hot weather conditions
Fresh-air heating through cavity		<ul style="list-style-type: none"> ✓ Fresh-air exchange to keep the air quality of building; ✓ Averagely it shows the highest air exchange rate; ✓ The time needed to approach steady condition is relatively shorter; 	<ul style="list-style-type: none"> • Only the upper part of room is heated, while the height is dependent on the window; • The temperature of the hot layer is relatively low; 	Regularly occupied buildings under cool weather conditions
Fresh-air heating through room		<ul style="list-style-type: none"> • Fresh-air exchange to keep the air quality of building; • The temperature of the hot layer is relatively higher; 	<ul style="list-style-type: none"> ✓ Only the upper part of room is heated, while the height is dependent on the window; ✓ The air exchange rate is relatively low; 	Regularly occupied buildings under cold weather conditions
Sealed heating		<ul style="list-style-type: none"> ✓ Heat the whole room from ceiling to the floor; 	<ul style="list-style-type: none"> • No fresh air supply; • The time needed to approach steady condition is relatively long; 	Non-regularly occupied buildings like storages

ROOF SOLAR CHIMNEY

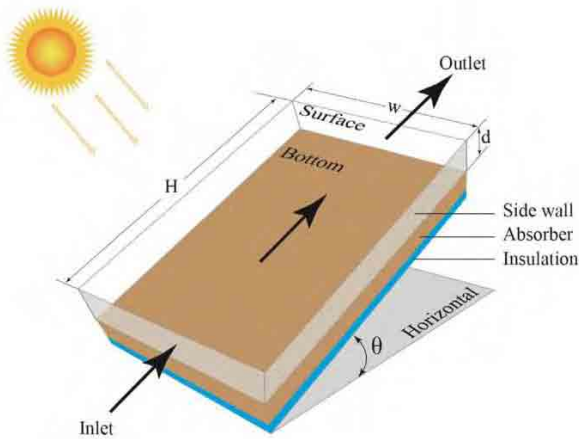


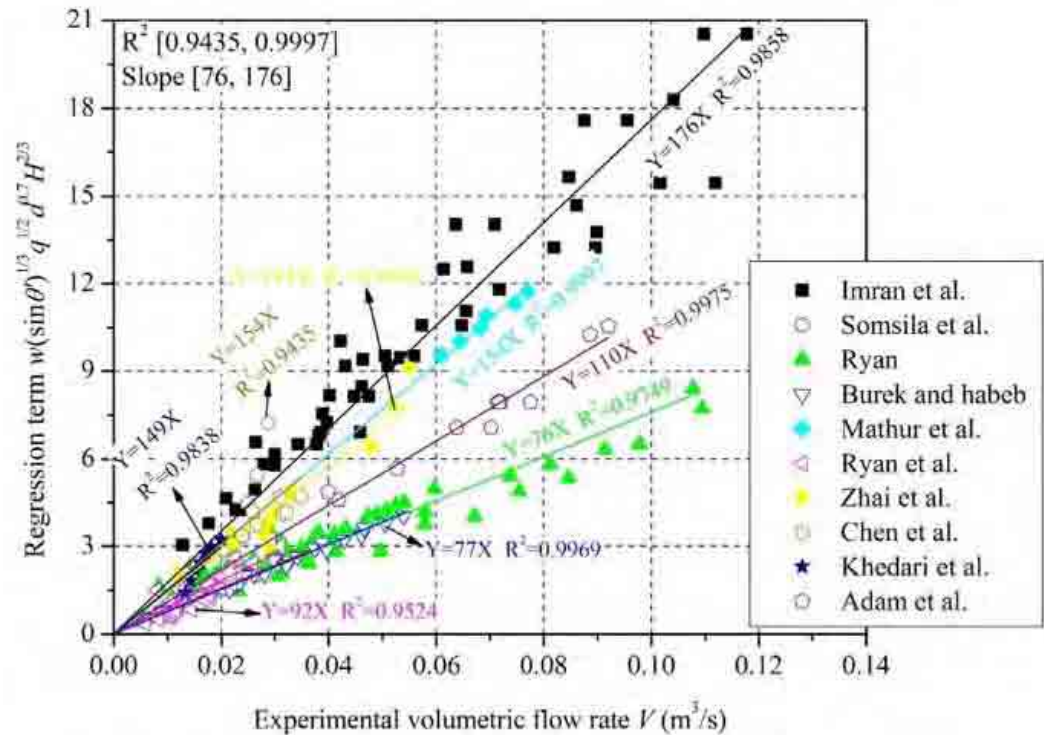
Table 2

A summary of influencing factors and their testing ranges in literature.

Influencing factor	Unit	Studied range	Test range ^a
Inclination angle (θ)	°	10–90	15–60 [20]; 30–45 [21]; 10–90 [22]
Cavity gap (d)	m	0.02–0.6	0.05–0.15 [20]; 0.1–0.3 [21]; 0.02–0.372 [22]
Height (H)	m	0.521	1.0–2.0 [22]; 0.521–2.07 [23]; 1.0–2.07 [24]
Height/gap ratio (H/d)	—	2.5–103.5	13.3–40.0 [20]; 6.7–20.0 [21]; 10.0–40.0 [22]; 13.3–40.0 [23]; 10.0–40.0 [24]
Inlet area (A_{in})	m ²	0.019	0.1–0.3 [20]; 0.1–0.3 [21]; 0.02–0.372 [22]
Outlet area (A_{out})	m ²	0.02	0.1–0.3 [20]; 0.1–0.3 [21]; 0.02–0.372 [22]
Inlet/outlet ratio (A_r)	—	0.128–7.8	0.128–7.8 [19]
Radiation heat (q)	W/m ²	50–1057	150–750 [20]; 400–800 [22]; 188–750 [23]; 73–374 [29]; 100–500 [30]

Note.

^a This table only includes the data with parametric studies, ignoring



$$V = \frac{w(\sin\theta')^{1/3} q^{1/2} d^{0.7} H^{2/3}}{\text{Slope}}, \text{ where } \theta' = \begin{cases} \theta, & \theta \leq 52.5 \\ 105 - \theta, & \theta > 52.5 \end{cases}; \text{ Slope in Eq. (18)}$$

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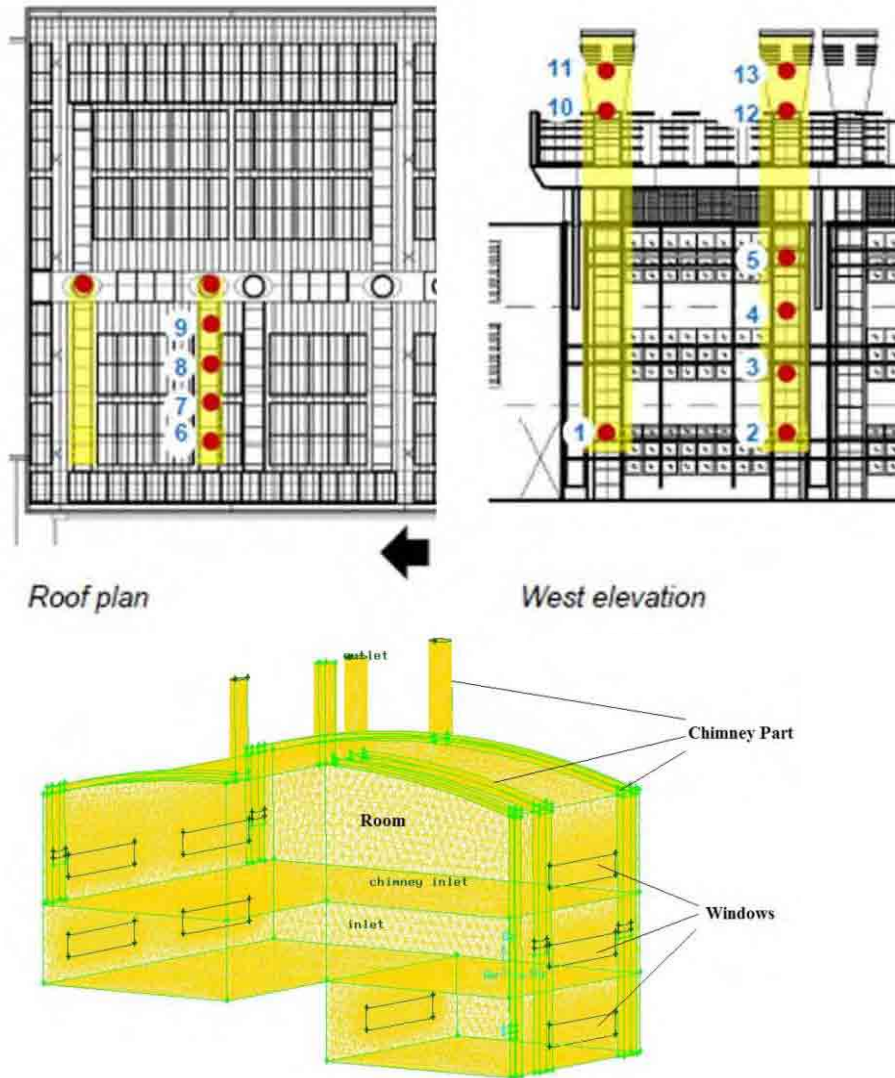
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ZERO ENERGY BUILDING IN SINGAPORE

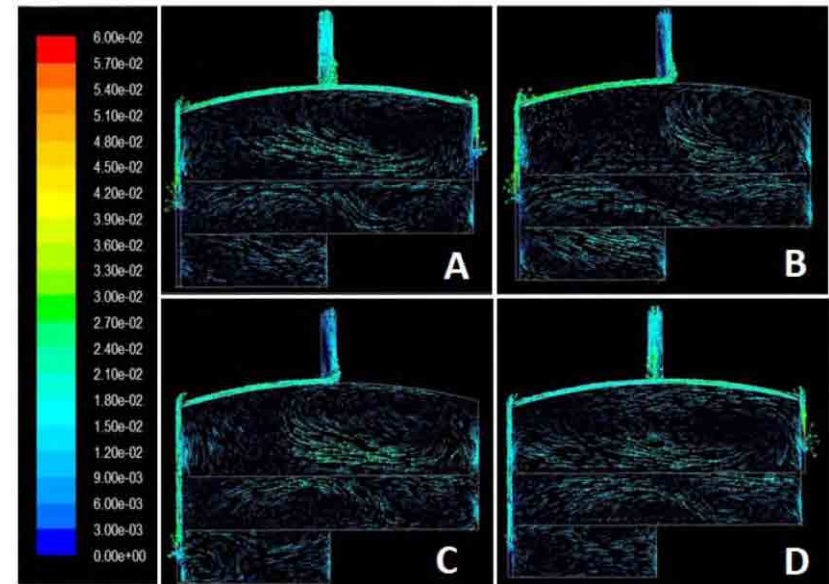


- Singapore Building and Construction Authority (BCA) and National University of Singapore built the first Zero Energy Building in the tropics.
- The aim of these studies is to **provide a reference guideline** on integrating solar chimney design for room ventilation especially in tropical climate.

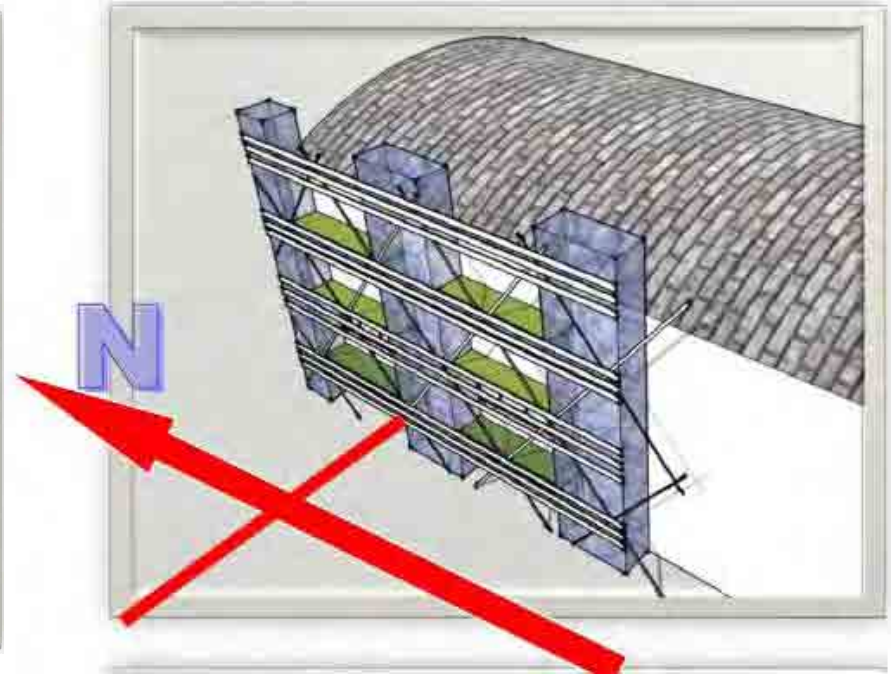
ZERO ENERGY BUILDING IN SINGAPORE



A combined research of experimental and numerical investigation.

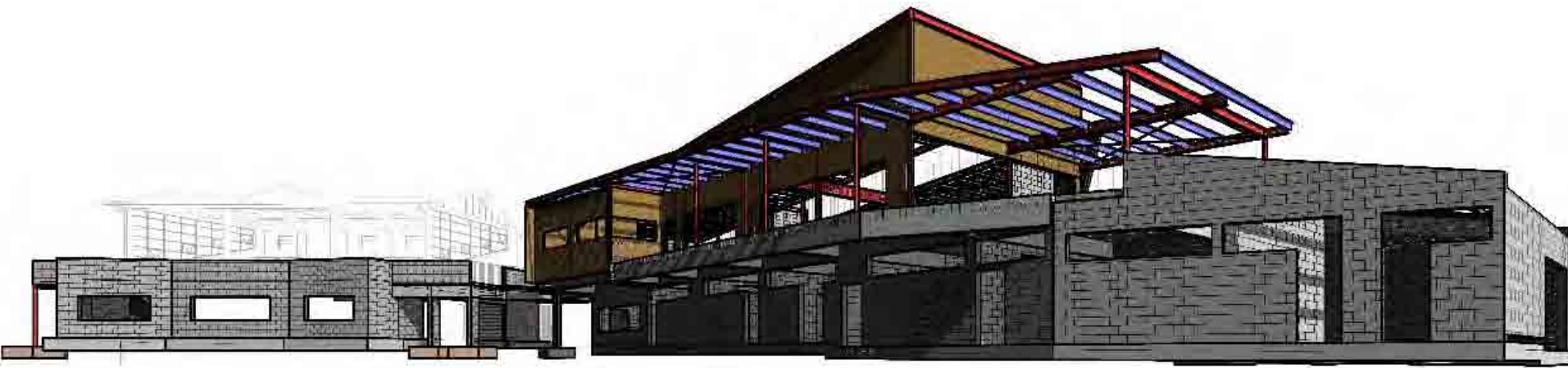


WHAT WE GOT FROM THE ANALYSIS



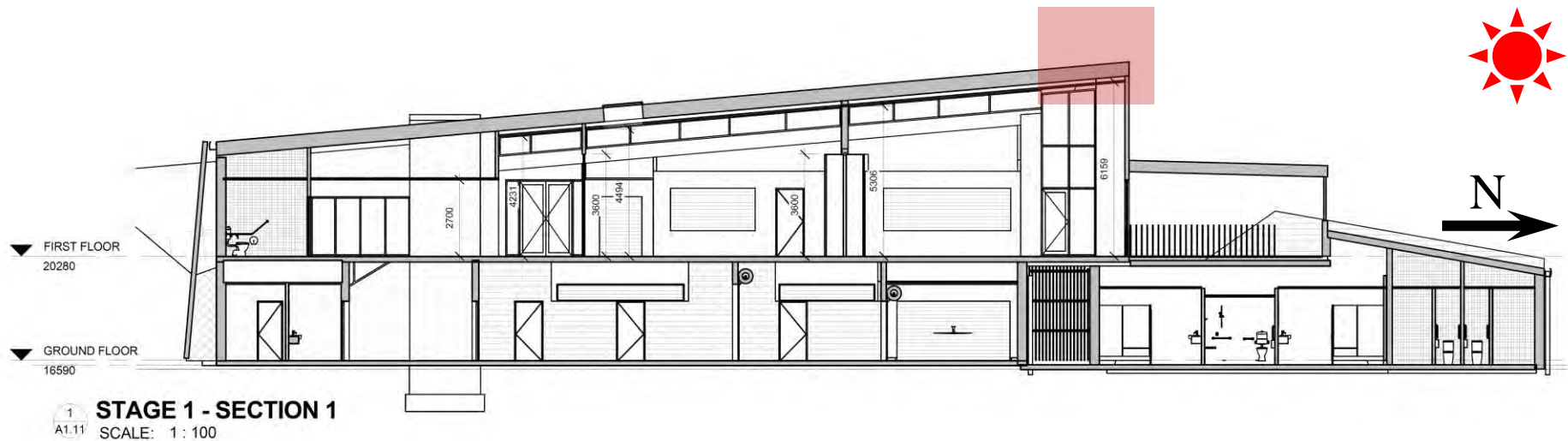
KINSTON CITY COUNCIL BUILDING

- **GH Soppet Pavilion Mentone Reserve** is located at Brindisi Street, Mentone, VIC 3194, Australia.
- The building includes two floors, namely ground floor and the 1st floor.



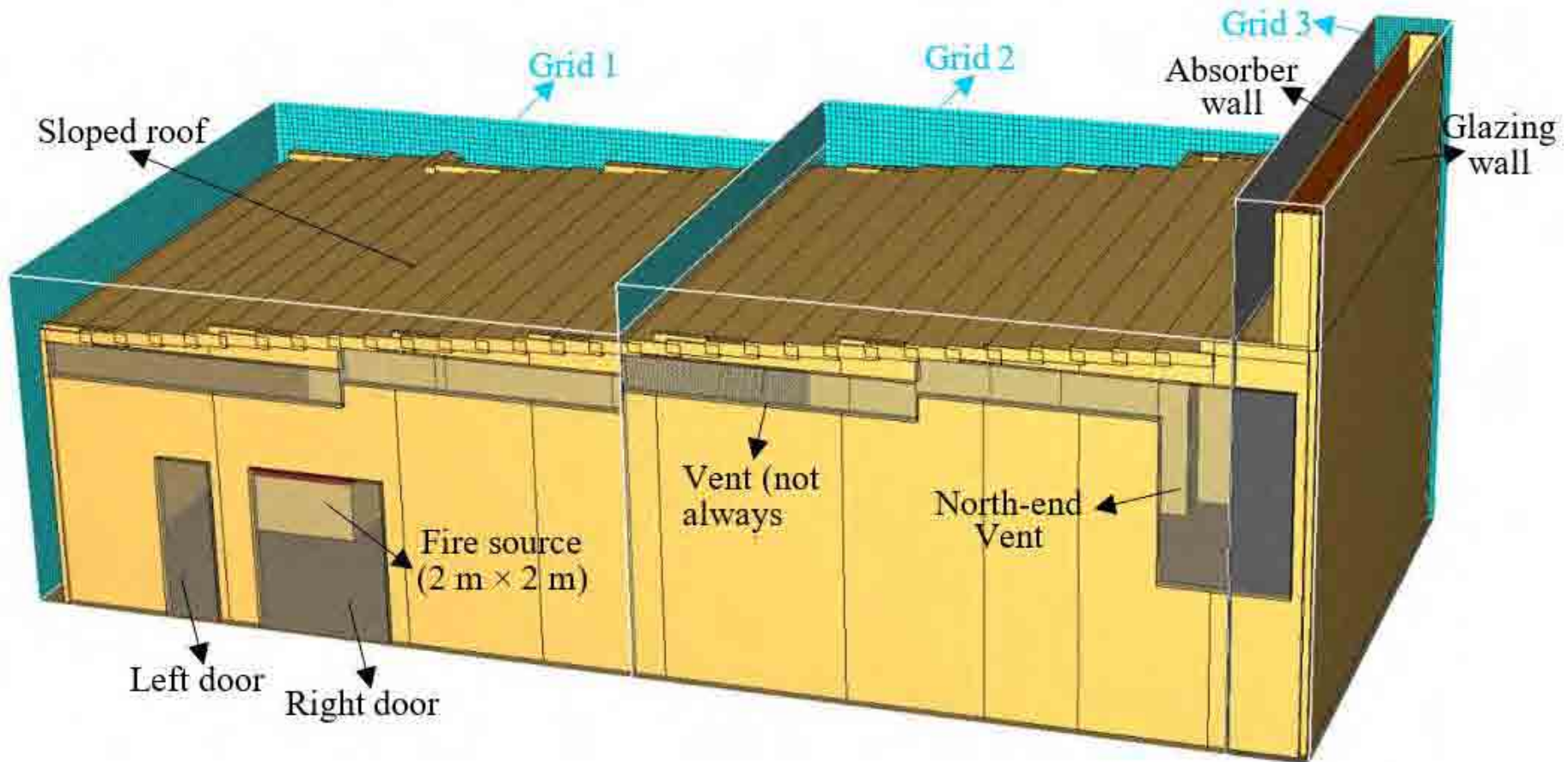
TARGET LOCATION OF SOLAR CHIMNEY

- The purpose of this report is the **optimization design of a potential solar chimney** for this building to enhance the indoor natural ventilation, and then to improve the indoor air quality and save the energy consumption.



NUMERICAL METHODOLOGY

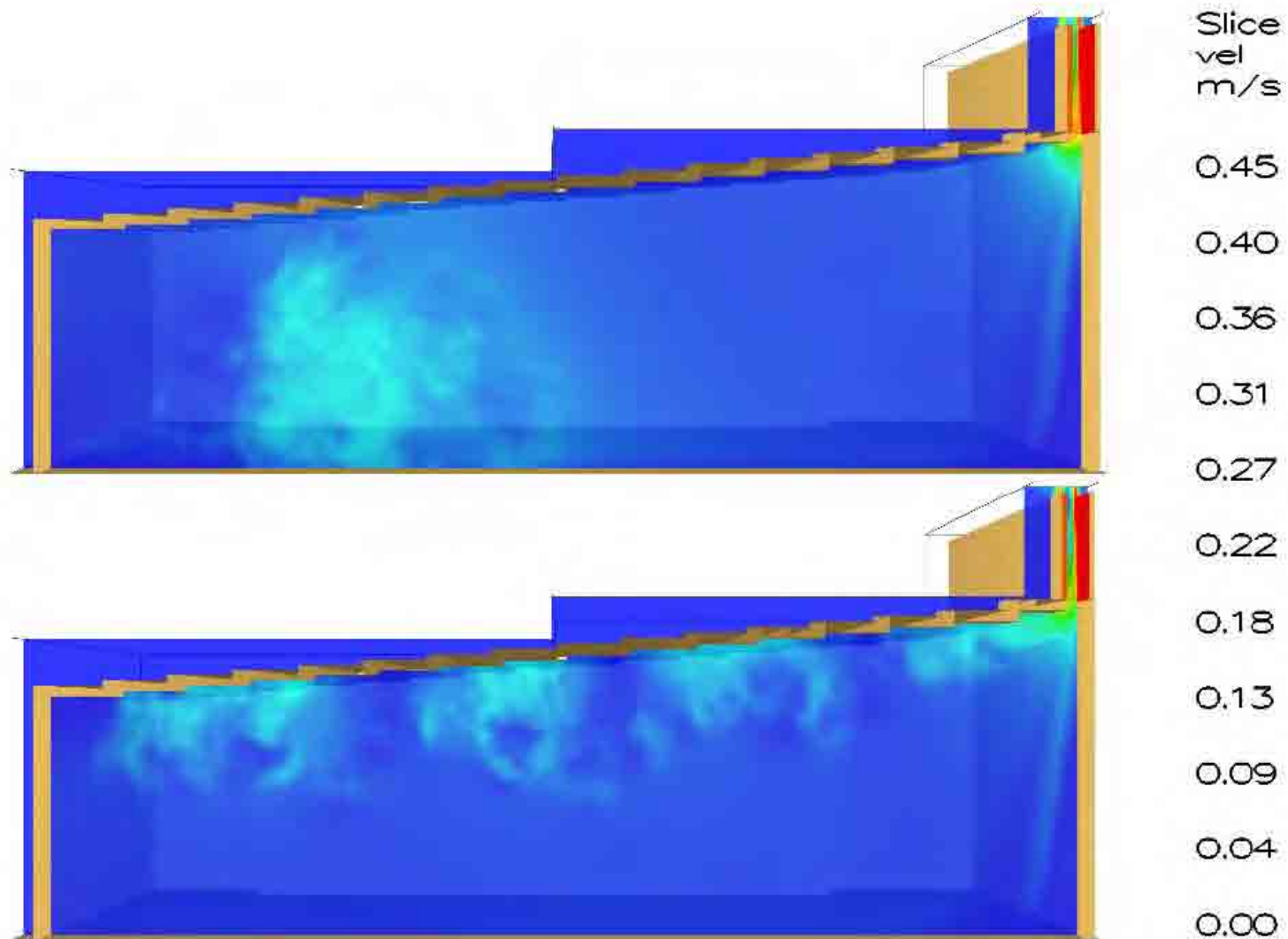
- Navier-Stokes equations provide the basis to describe the airflow under different situations, which are the fundamental of the modern computational fluid dynamics



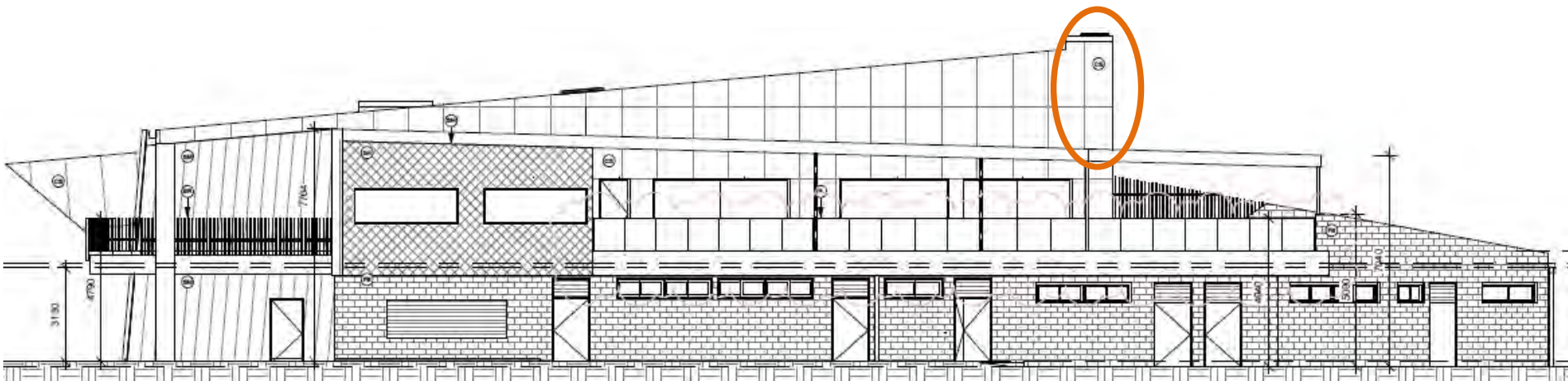
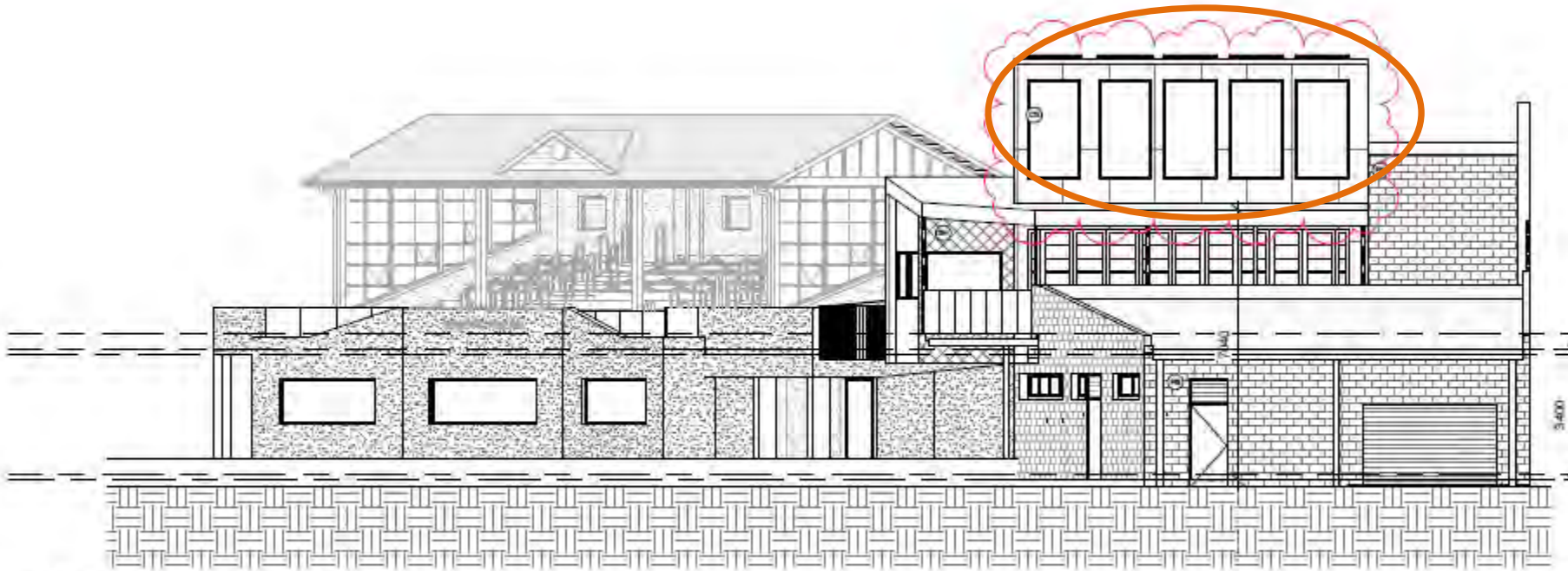
NUMERICAL SCENARIOS

No.	Parameter	Description	Studied range	Interval	Unit
1-13	Cavity gap	The distance between the absorber and glazing walls	0.1-1.6	0.1-0.2	m
14-18	Cavity height	The vertical height of the chimney cavity from the bottom to top	1.0-3.0	0.5	m
19-25	Door width for air supply	The area of the door opened for air supply with a height of 2.7 m	1.1-7.1	1.0	m
26-31	Vent width for air supply	The area of the vent opened for air supply with a height of 0.6 m	4.0-22.4 ^a	3.65	m
32-36	Location of solar chimney	For a 2.0 m high solar chimney, the height of the part below the roof	0-2.0	0.5	m
37-41	Solar radiation	The solar radiation on the glazing wall	200-1,000	200	W/m ₂

NUMERICAL OUTPUT



ADOPTION



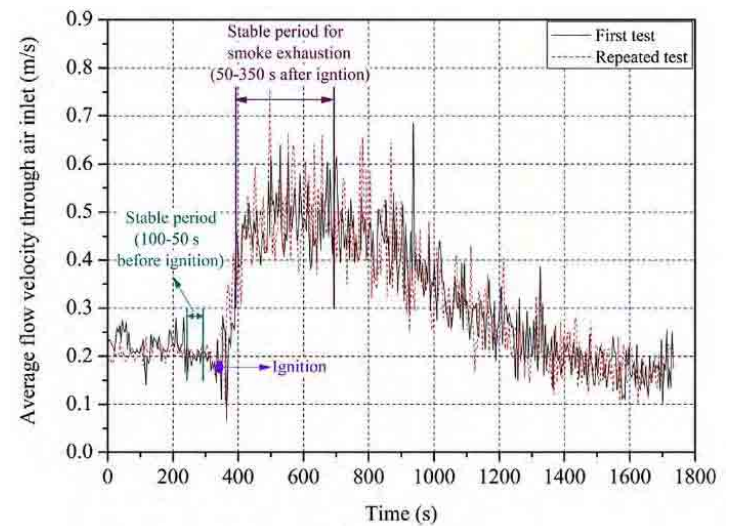
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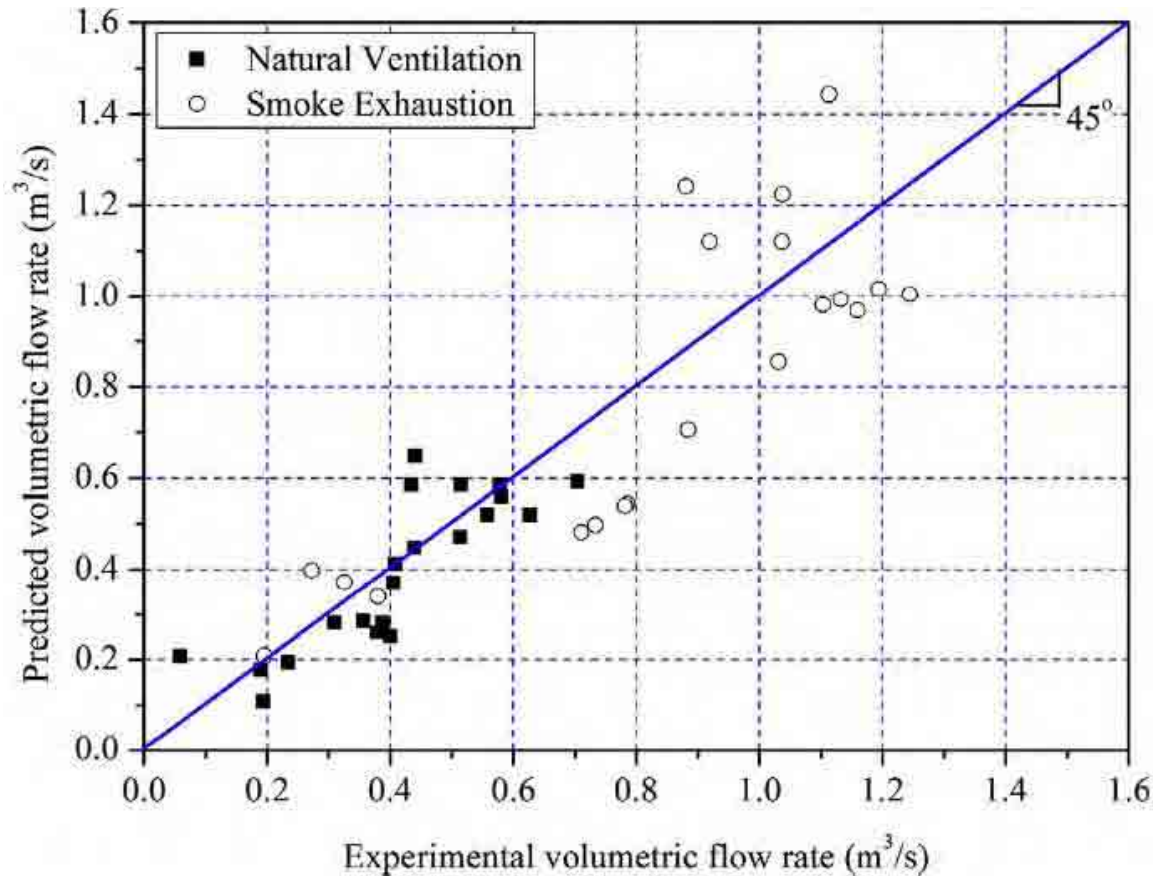
SOLAR CHIMNEY AND FIRE SAFETY

- Natural smoke exhaustion system is following the **same principle** with solar chimney, namely **thermal buoyancy**. Solar chimney may be adopted for both natural ventilation and smoke exhaustion.
- Smoke is one of the most deadly hazards for occupants under fire conditions, while the death due to smoke inhalation is higher than direct burning.

EXPERIMENTAL TEST

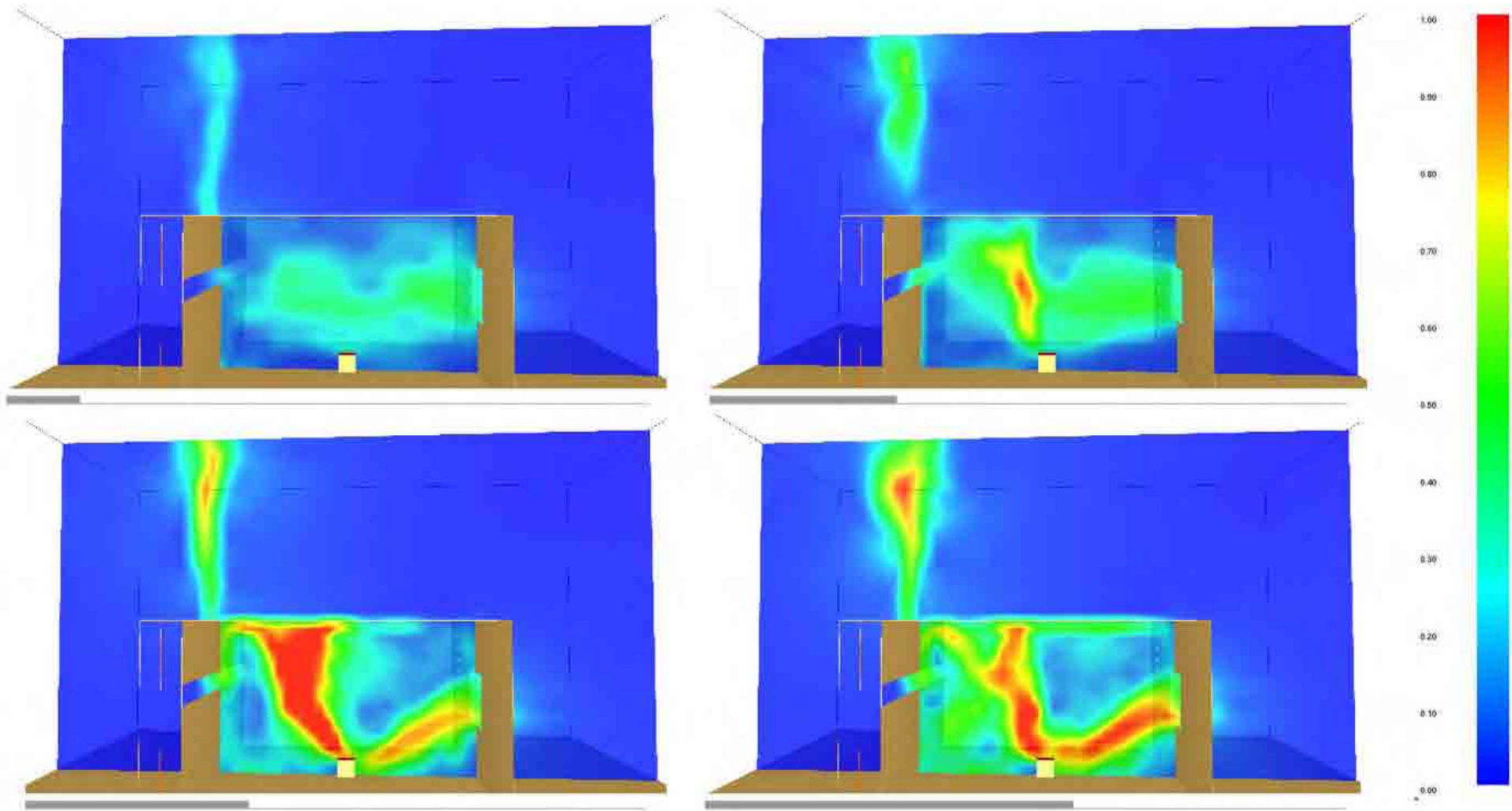


EMPIRICAL MODEL



$$V_w = 0.0029[1.88 - (h_{in} - 1.68)^2]w(dH)^{2/3}(\tau \dot{Q}_{rad}'' + 0.55\dot{Q}_{fire}'')^{1/3}$$

NUMERICAL OUTPUTS



STILL NEED IMPROVEMENT

- Solar chimney can be used for a part of wall or roof to enhance the natural ventilation, while limitation also applies with its applications:
- It cannot be adopted to the façade **requiring the view** as it is not transparent;
- The high absorption area it has, the better performance it will show. So a big absorption area is favourable.

That is the reason we start to do the research on double-skin façade.

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CONCLUSIONS

- Solar chimney is a reliable and efficient renewable energy system, which can help to reduce the energy consumption for **life-time usage** with limited extra construction cost (<15%);
- Research efforts are still urgently needed, with the direction of **new expanded function and higher energy efficiency under local climate**.

*Thank
You*



**QUESTIONS ARE
WELCOME**