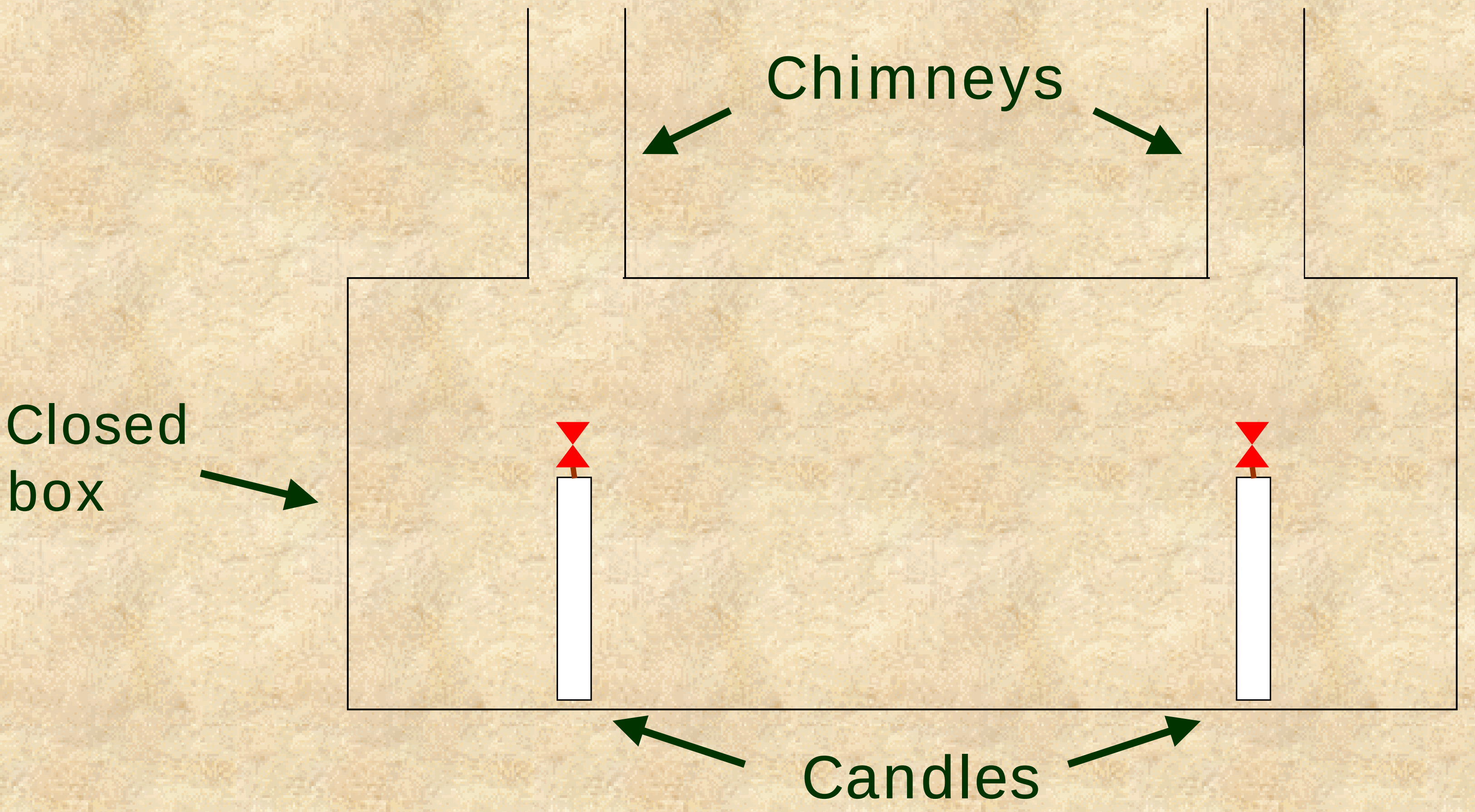
Experimental approach

Apparatus:



Materials we used:

1. Chimneys: Metal pipes
   Paper
2. Box: Wood
   Plexiglas
   Corks
3. Wax candles

Experiments with variation of parameters

Varied parameters:

1. Height of the chimney
2. Radius of the chimney

Dimensions of used chimneys:

HEIGHT (cm)	RADIUS (cm)
40	6
40	4
40	1.7
30	2.2
28	3.5
14.5	2.2

Conditions for phenomenon occurence:

1. Box must be fully closed

2. The flame must be on the axis of the chimney

3. Height of the candles must be constant

Explanation

The air movement can be divided on:

1. Pressure increase
2. Air density decrease
3. Pressure decrease
4. Pressure equalizing

1. Pressure increase

- Process of candle burning:

$$C_{35}H_{72}+53O_2\rightarrow 35CO_2+36H_2O+Q$$

- For gases ratio we have:

$$53\ \text{mol}_b \rightarrow 76\ \text{mol}_a$$

- From equation of state follows:

$$pV = nRT$$

$$\frac{p_2}{p_1} = 1.43\frac{T_2}{T_1} \quad \Rightarrow \quad \boxed{p_2 > p_1}$$

T_1 – temperature before ignition

T_2 – temperature during burning

T_1 – pressure before ignition

T_2 – pressure during burning

2. Air density decrease

- During heating air density decreases:

$$\rho = \frac{\rho_0}{1+\alpha T}$$

ρ – Density during heating

ρ_0 – Density before heating

α – Coefficient of thermal expanding

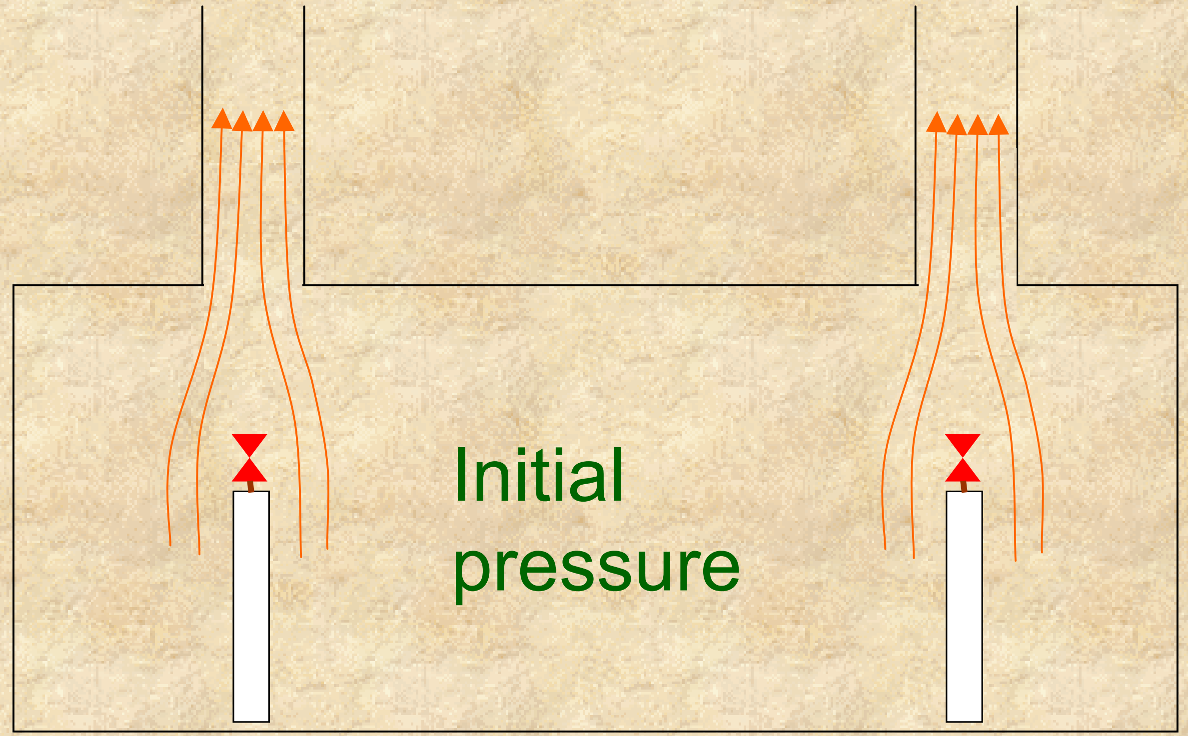
T – Air temperature

$$\Rightarrow \rho < \rho_0$$

- When ignited, the candle “sends” the air in the chimney

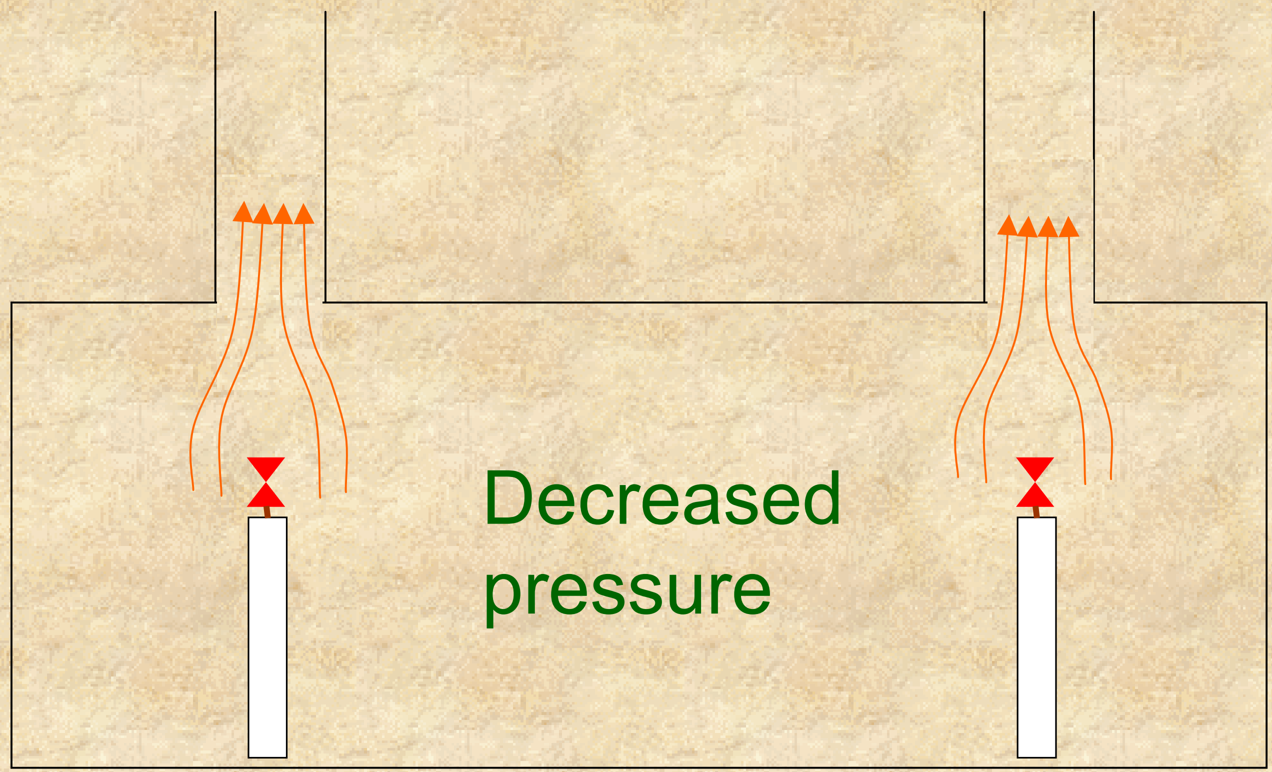
3. Pressure decrease

- Pressure and buoyancy increase causes air flow:



- Air is pushed out through both chimneys

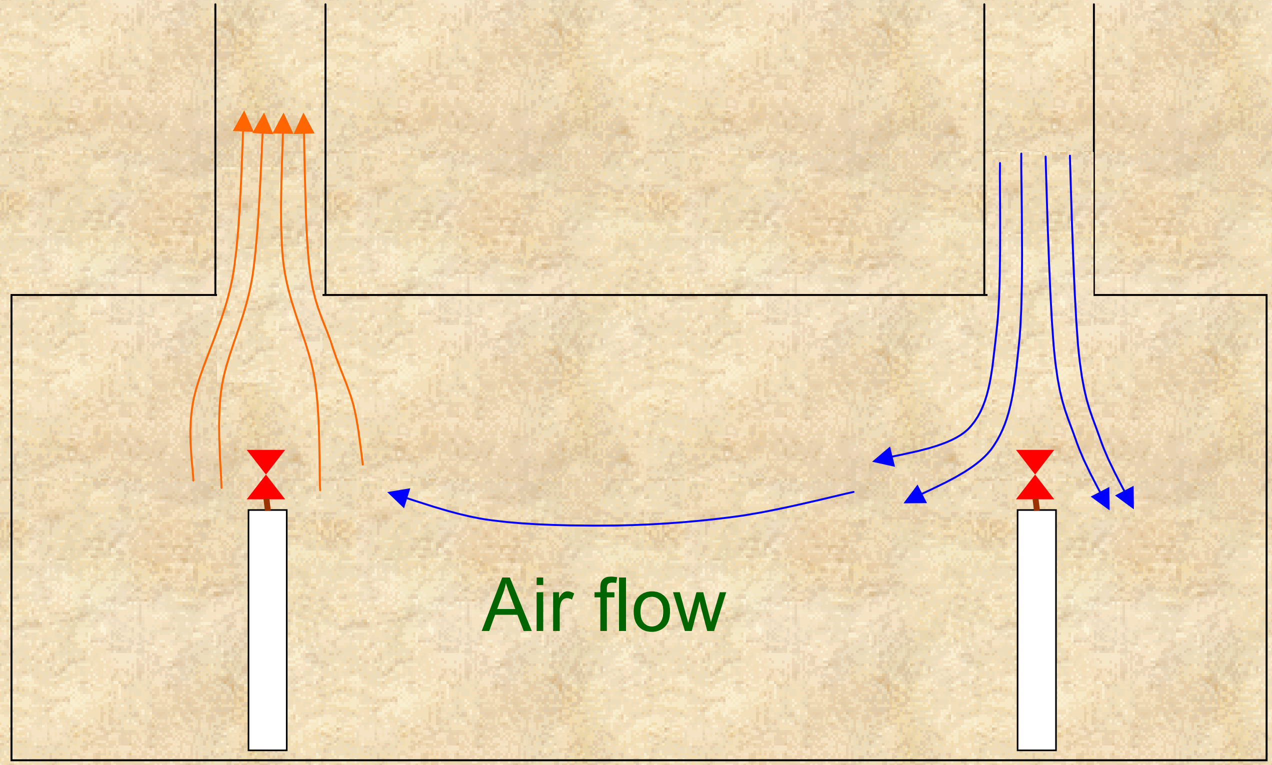
- Constant air flow causes pressure decrease in the box:



- Air flow slows down

4. Pressure equalizing

- External pressure is higher than pressure in the box → air rushes in through one of the chimneys:



- Pressures are equalizing

Which chimney will prevail?

- The answer to this question depends on the cross-section and height combinations:

1. $S_1 > S_2$ and $h_1 = h_2$
2. $S_1 = S_2$ and $h_1 > h_2$
3. $S_1 > S_2$ and $h_1 \neq h_2$
4. $S_1 = S_2$ and $h_1 = h_2$

S_i – cross-section

h_i – height

$S_1 > S_2$ and $h_1 = h_2$

- Through the broader chimney flow is slower
- Pressure will equalize through it

$S_1 = S_2$ and $h_2 > h_1$

- In this case the flows are equal
- The pressure will equalize through lower chimney

$S_1 > S_2$ and $h_1 \neq h_2$

- This case has two subcases:

1. $h_1 > h_2$
2. $h_1 < h_2$

1. $h_1 > h_2$

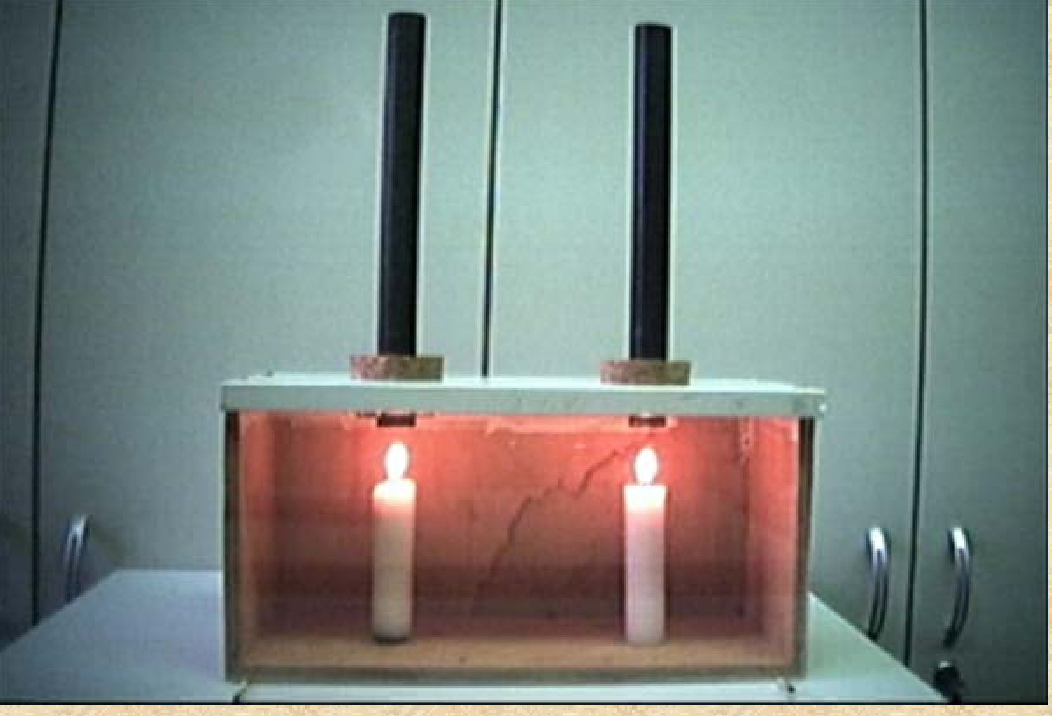
- Two possibilities occured:
    - The flame under smaller chimney becomes unstable
    - The flame under bigger chimney becomes unstable

2. $h_1 < h_2$

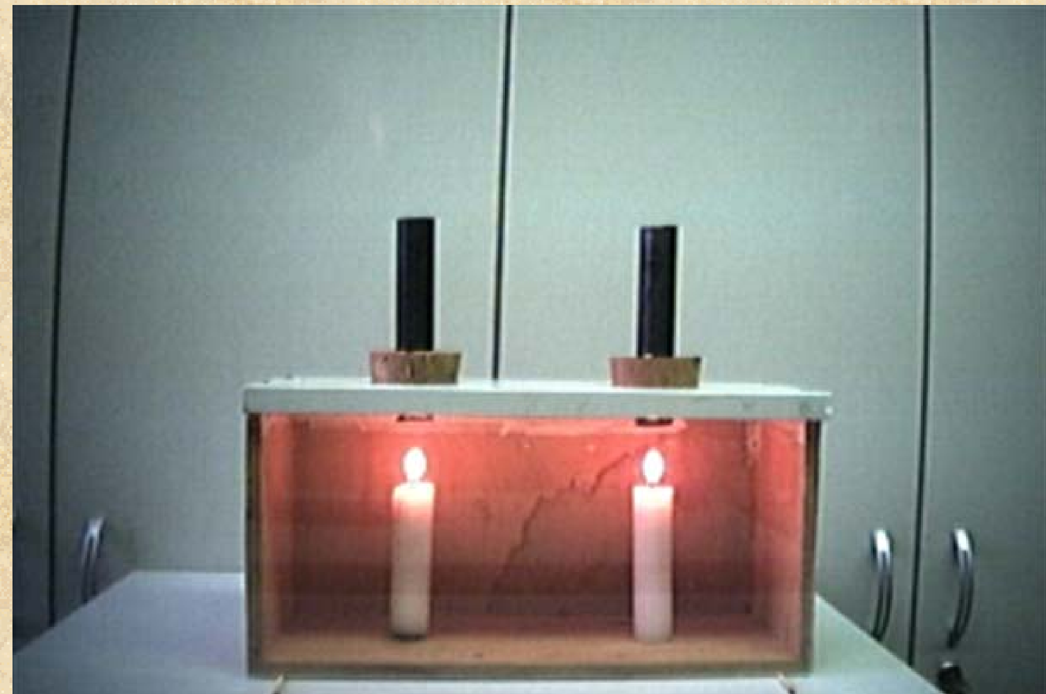
- The air will come in through smaller chimney due to smaller air mass and lower flow

$S_1 = S_2$ and $h_1 = h_2$

- In the ideal case pressure in the box would be diminished until:
  - The candles go out
  - It gets equalized through both chimneys
- The prevailing chimney cannot be determined a priori
- Imperfections in the apparatus cause one chimney to drag more



Equal height and cross-sections



Conclusion

- We can say that the observed effect of flame instability has two causes:
    1. Difference in pressures
    2. Difference in flows throuh the chimneys
- In some cases it is impossible to say which flame will become unstable, but in other we can predict that with great security