

MIXED VENTILATION SYSTEMS IN RESIDENTIAL BUILDINGS: APPLICATION OF THE DESIGN PRINCIPLES BASED ON prNP 1037-5

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Keywords: prNP 1037-5, Mixed ventilation, Ventilation rates, ACH, Ventilation systems, Dwellings

Abstract *In multi-family buildings in Portugal essentially mixed ventilation systems are used. However, this system does not currently have a document that supports its design. The mixed ventilation system envisaged in the prNP 1037-5 considers two situations a) base flowrate given by passive devices which will allow the dwelling to be swept by flow rates due to wind action (e.g. horizontal ducts between compartments located on opposite facades), b) peak flowrate given by mechanical extraction placed in service compartments (kitchen and toilet facilities).*

In this paper, through a simulation using the CONTAM software and based on experimental data of air permeability of ventilation devices, an application of the design principles of the mixed ventilation systems idealized in prNP 1037-5 is performed. A sensitivity analysis is carried out by varying some of the most significant parameters in mixed ventilation systems, such as: geographical location, orientation and elevation of the dwellings; positioning of interior doors, closed or open. It involves the annual simulation of air flows using representative environmental conditions of the continental Portuguese climate (four cities), and the production of indoor pollutants (water vapor and CO₂).

Through this simulation we intend to conclude, for example, what is proper condition (opened or closed) of interior doors and the recommended air intake flows.

1. INTRODUCTION

Ventilation is of great importance in defining the hygrothermal conditions of comfort, indoor air quality and in the energy consumption of heating and cooling.

Essentially, there are two types of systems: systems with natural ventilation (NV) and systems with mechanical ventilation (MV). Often, in Portugal the natural and mechanical ventilation systems are linked, forming mixed systems.

In the mixed ventilation systems, the permanent renewal of the air is ensured by cross ventilation, and the pollutants generated in service compartments (kitchen and toilet facilities) removed by the activation of individual air extraction fan. Thus, the exhaust indoor air to the outside is possible, as well as the extraction of the pollutants generated in the service compartments, minimizing the problems of Indoor Air Quality (IAQ) or the occurrence of condensation. In this case, the ducts in kitchens and toilets are dimensioned for extracting air. The activation of the fans by the occupants coincides with the use of the service compartments. In the remaining periods (non-operating fans), the fans obstruct the conduct of air extraction contributing for low natural ventilation flowrate of the house. This type of system is mainly used in dwellings.

Mixed ventilation systems have some advantages such as:

- Lower power consumption compared to the Centralized Mechanical Ventilation system (CMV);
- In the case of intermittent operation, high ventilation rates are only used when they are needed (use of service compartments).

They also have aspects that may be disadvantageous, such as:

- System cost (less than the CMV system, but larger than the NV system);
- Energy consumption (lower than the CMV system, but larger than the NV system);
- Noise level (higher than in the CMV and NV systems);
- Maintenance cost (higher than the NV system, but smaller than the CMV system);
- Currently, they are working intermittently, not ensuring continuously the required ventilation flowrate;
- As there are no standards or calculation methods well established for this type of systems, they are normally very poorly implemented leading to very low ventilation air flow rates when the fans are not operating, because ventilation ducts are blocked by the fans.

This paper aims to support the development of prNP 1037-5 [1], in particular, to characterize the operation of the current mixed ventilation systems (air self-adjustable inlets devices located in the main compartments - bedrooms and living room - , and intermittent mechanical exhaust in service compartments).

2. DESCRIPTION OF THE BUILDING AND THE VENTILATION SYSTEM SIMULATED

The adopted ventilation system mainly has the following characteristics [1]:

- Consideration of two independent ventilation sectors: one sector consists of bedrooms, living rooms and toilet facilities. The other sector is formed by the kitchen to ensure the

- absence of migration of the pollutants produced there to other rooms;
- Low air permeability of the window frames according to class 4 of EN 12207: 1999 [2] and main entrance door according to NP 1037-1 [3];
- Intake air through the air self-adjustable inlet devices (for 2 Pa pressure difference) in the main compartments and an air inlet in the kitchen dimensioned for the maximum exhaust air flow rate;
- Intake and exhaust air flow rates in accordance with NP 1037-2 [4];
- Operation of mechanical ventilation only for the maximum air flow rate of the kitchen and toilet facilities.

The solution where there are only main compartments in the same ventilation sector it is not recommended, avoiding the situation in which the air flow is established from a main compartment to another main compartment, where air is exhausted. However, in this ventilation scheme that is not always possible, because the swept provided by the wind can drive the stale air of a compartments to others. In this study, such possibility was assumed because we want to find a scheme to ensure better ventilation conditions than currently practiced in current buildings and with lower resources consumption.

For the simulation of systems, we selected a four-level multifamily building with 8 apartments (T3 typologies - 3 bedrooms - in the left side and T2 typologies on the right one), inserted in the urban area and located on the outskirts of Porto. The proposed ventilation system had the following characteristics:

- Air intake through air self-adjustable inlet devices (located 2 m high); three devices in each facade with "module" 6 l/s - a reference flow rate (21.6 m³/h) at 2 Pa pressure difference;
- An air inlet at the outer door of the kitchen, installed at the bottom of the door;
- Mechanical exhaust of the toilet with an air flow rate of 45 m³/h;
- Mechanical exhaust of the kitchen with an air flow rate of 296 m³/h (180 m³/h_{kitchen} + 116 m³/h_{water heater}).

The characteristics of windows and doors, particularly the dimensions and bottom gap of the interior doors, the pressure coefficients and the operating hours of mechanical exhausts are described in [5].

The selected apartment typology T2 has a volume of 161.68 m³, see Figure 1.

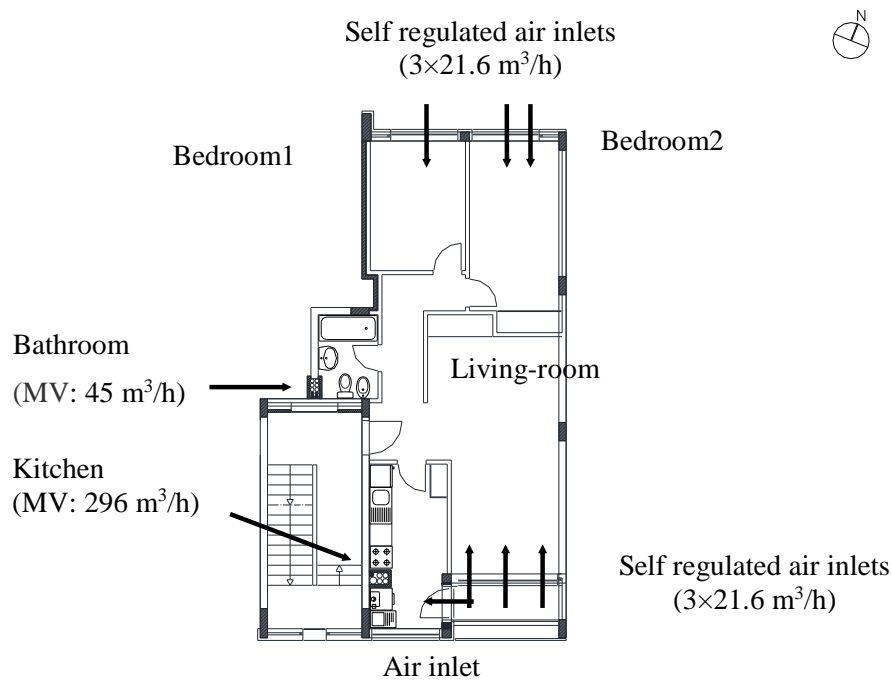


Figure 1. T2 type apartment - ventilation system

3. SENSITIVITY ANALYSIS

Through simulation using the CONTAM software [6], we performed a sensitivity analysis by varying some of the most significant parameters in the adopted ventilation system, such as inlet air flow rates, orientation of the apartment, area of the air inlet in the kitchen and positioning of the interior doors (open or closed).

The annual simulation of airflow uses representative environmental conditions of the Portuguese continental climate (four cities) and also involves the production of indoor pollutants (water vapor and CO_2).

The conditions and simplifications adopted in the simulations were as follows:

- Emission of pollutants by the occupants (2 adults and 2 children) and activities as [5]. Children were considered in Room 2;
- Constant and homogeneous inner temperature (20°C ; monozone model);
- Coatings without hygroscopicity;
- When required, interior doors closed with bottom gap of 8 mm;
- Weather files Energyplus for the four selected cities;
- Interaction of the apartment studied with the building only through the stairwell.

Simulated ventilation systems, the intake air flow rates and the respective air change rate (ACH) are presented in Table 1.

Table 1. Air flow rates and air change rates (ACH) depending on the simulated ventilation systems

Type system		City	Air flow rate ratio in the rooms (q_{real}/q_{proj})				Average	ACH average
			4th level	3rd level	2nd level	1st level		
1	BASELINE SYSTEM (orientation of the main facade to 150°; interior doors opened; self-regulating air inlet in the kitchen during func. ex. mec. ¹)	Bragança	0.50	0.47	0.45	0.38	0.63	0.32
		Porto	0.50	0.47	0.45	0.39		
		Lisboa	1.15	1.11	1.06	0.92		
		Faro	0.64	0.60	0.57	0.47		
2	ENHANCEMENT OF ADMISSION AIR FLOW RATES AT 30% (system 1 with an increment of air flow rates at 30%)	Bragança	0.58	0.55	0.52	0.44	0.74	0.35
		Porto	0.59	0.55	0.52	0.46		
		Lisboa	1.36	1.31	1.25	1.08		
		Faro	0.75	0.71	0.66	0.55		
3	ENHANCEMENT OF ADMISSION AIR FLOW RATES AT 60% (system 1 with an increment of air flow rates at 60%)	Bragança	0.66	0.63	0.59	0.50	0.85	0.38
		Porto	0.67	0.63	0.60	0.52		
		Lisboa	1.56	1.51	1.44	1.23		
		Faro	0.86	0.81	0.76	0.63		
4	ENHANCEMENT OF AD. AIR FLOW RATES AT 60% AND BEDROOMS WITH CLOSED DOORS (system 1 with an increment of flow rates at 60% and bedrooms with closed doors)	Bragança	0.51	0.48	0.46	0.40	0.62	0.30
		Porto	0.52	0.49	0.47	0.41		
		Lisboa	1.13	1.06	0.97	0.80		
		Faro	0.63	0.59	0.56	0.47		
1a	BASELINE SYSTEM WITH CHANGING THE APARTMENT ORIENTATION (system 1 with orientation of the main facade to 240°)	Bragança	0.31	0.28	0.27	0.23	0.46	0.25
		Porto	0.44	0.40	0.35	0.29		
		Lisboa	0.95	0.80	0.68	0.51		
		Faro	0.55	0.49	0.44	0.35		
5	ENHANCEMENT OF AIR FLOW RATES AT 60% AND CHANGING THE KITCHEN AIR INLET (system 1 with fixed air inlet in the kitchen ²)	Bragança	0.60	0.56	0.53	0.44	0.83	0.53
		Porto	0.63	0.59	0.56	0.48		
		Lisboa	1.57	1.52	1.45	1.25		
		Faro	0.86	0.80	0.74	0.62		
6	ENHANCEMENT OF AIR FLOW RATES AT 60% AND CHANGING THE KITCHEN AIR INLET (system 5 with the door of the kitchen closed)	Bragança	0.55	0.51	0.47	0.37	0.76	0.42
		Porto	0.55	0.51	0.47	0.38		
		Lisboa	1.53	1.47	1.39	1.18		
		Faro	0.79	0.73	0.67	0.53		

Note 1- Fixed area of 60 cm² in a self-regulating air inlet according to French commercial device.
 Note 2- Fixed air inlet with 331 cm² sized for the maximum flow rate and for a 10 Pa pressure difference.

From the analysis of Table 1, the following main conclusions are obtained:

- Generally, intake air flow rates are well below the design flow; systems 3 and 5, with an increase of 60% of the inlet air flow rate, are those in which the inlet air flow rate most approach the design flow;
- Due to wind action, the 1st level has lower inlet air flow rate as opposed to the 4th level which has the highest intake air flow rate;
- The city of Lisbon has greater intake air flow rates at all levels, due to a more intense action of the wind;
- Comparing the systems 1 and 1a, it can be concluded that the orientation of the facades has a relevant function in the intake air flow rate;
- Comparing the systems 3 and 4 and 5 and 6, it can be concluded that the closing of the doors restricts the inlet air flow rate;
- Comparing the average inlet air flow rates of the systems 3 and 5, it can be concluded that it is not necessary a permanent fixed air inlet in the kitchen (this air inlet it is only necessary to prevent high discomfort in the main compartments due to the kitchen fan operation);

- Generally, the systems do not reach the minimum $ACH (\geq 0.4 \text{ h}^{-1})$ stipulated in Portuguese legislation [7]; systems 3, 5 and 6, with an increase in 60% in the inlet air flow rates, are those that approach or exceed the minimum.

In relation to the system 1 (baseline system), it is presented in Figure 2 the frequency of intake air flow rate in bedroom 1 (Bragança, 1st level). It is concluded from the figure that, although rarely the flow rate is greater than the intake air flow rate ($21.6 \text{ m}^3/\text{h}$) in about 50% of the time, the air flow rate is less than $2 \text{ m}^3/\text{h}$. It is observed that the air inlet allows a reverse air flow rate (negative flow), favoring cross-ventilation, though with reduced air flow rate.

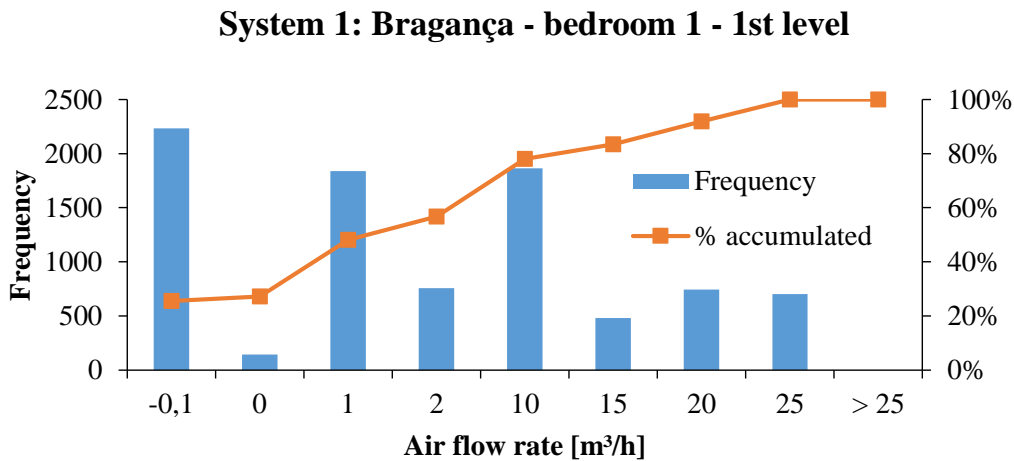


Figure 2. Ventilation system 1: Bragança, bedroom 1, 1st level - Air flow rate in the inlet

In the same system, is shown in Figure 3 the frequency of relative humidity in the kitchen (Bragança, 1st level). It is found that approximately 86% of the time the relative humidity is above 70% (recommended limit value in [8]) denoting a moist compartment facilitating to a fungal growth.

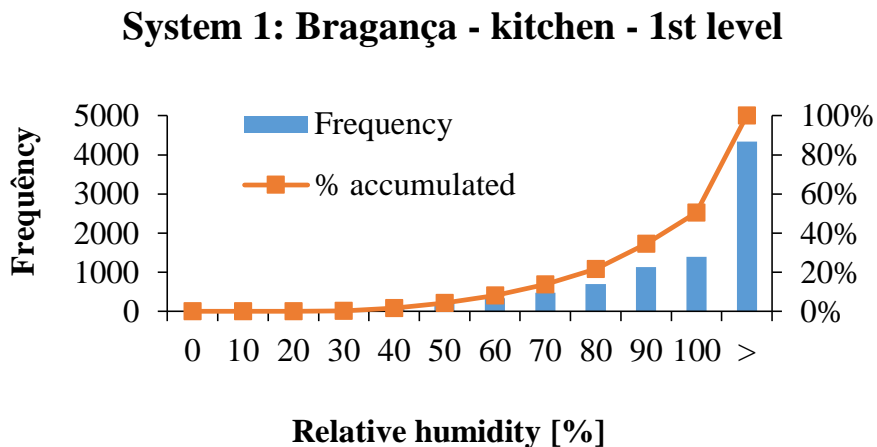


Figure 3. Ventilation system 1: Bragança, kitchen, 1st level - Relative humidity

Although not displayed, the bedroom 1 graph registers approximately the same percentage of time that exceeds 70% of relative humidity.

Regarding the system 1a, it is presented in Figure 4 the frequency of the CO₂ concentration in the kitchen (Bragança, 1st level). It is found that about 85% of the time the CO₂ concentration exceeds 1250 ppm (recommended limit value in [9]) denoting a compartment with a very poor IAQ.

System 1a: Bragança - kitchen - 1st level

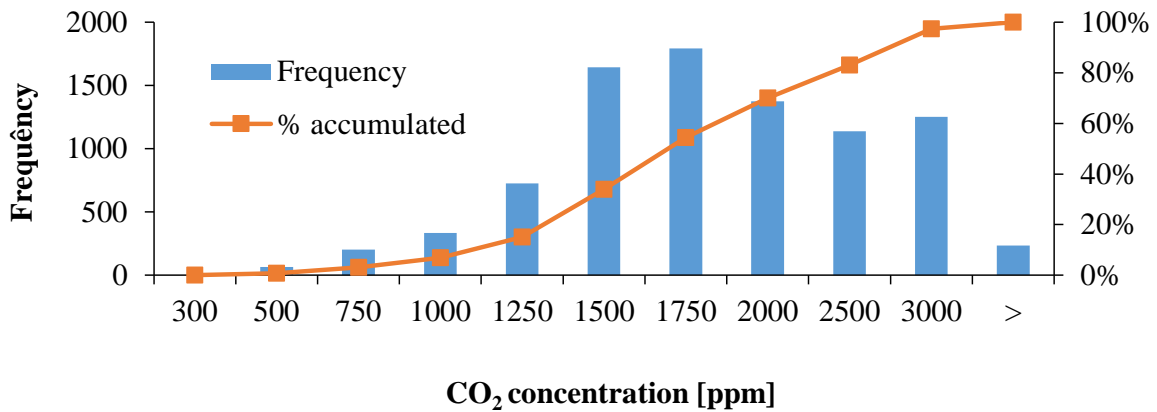


Figure 4. Ventilation system 1a: Bragança, kitchen, 1st level - CO₂ concentration

Figure 5 shows that, according to Energyplus files used, the city of Lisbon has predominant wind direction in octants north favoring the action of wind on the façades of the apartment in the study. The other three cities have a distribution that does not favor any particular direction.

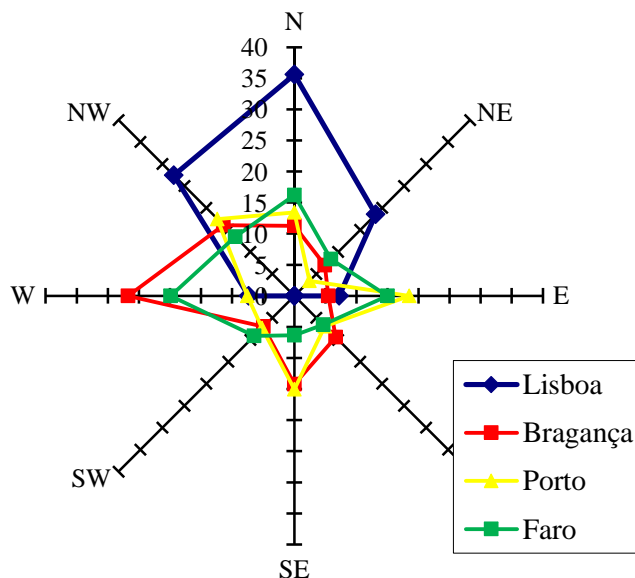


Figure 5. Wind: occurrences per direction in the four cities analyzed

In relation to the system 5, it is presented in Figure 6 the pressure-air flow rate relationship for the permanent fixed air inlet of the kitchen on the 1st level (Bragança, 1st of January). In the period of operation of mechanical exhaust (7:00 a.m. to 7:30 a.m. and 7:00 to 9:00 p.m.) the average flow on the air inlet is $142 \text{ m}^3/\text{h}$ and outside this period $52 \text{ m}^3/\text{h}$. In the system 3 (self-regulating air inlet opening only in the period of operation of the mechanical exhaust), the average flow in the air inlet is $87 \text{ m}^3/\text{h}$.

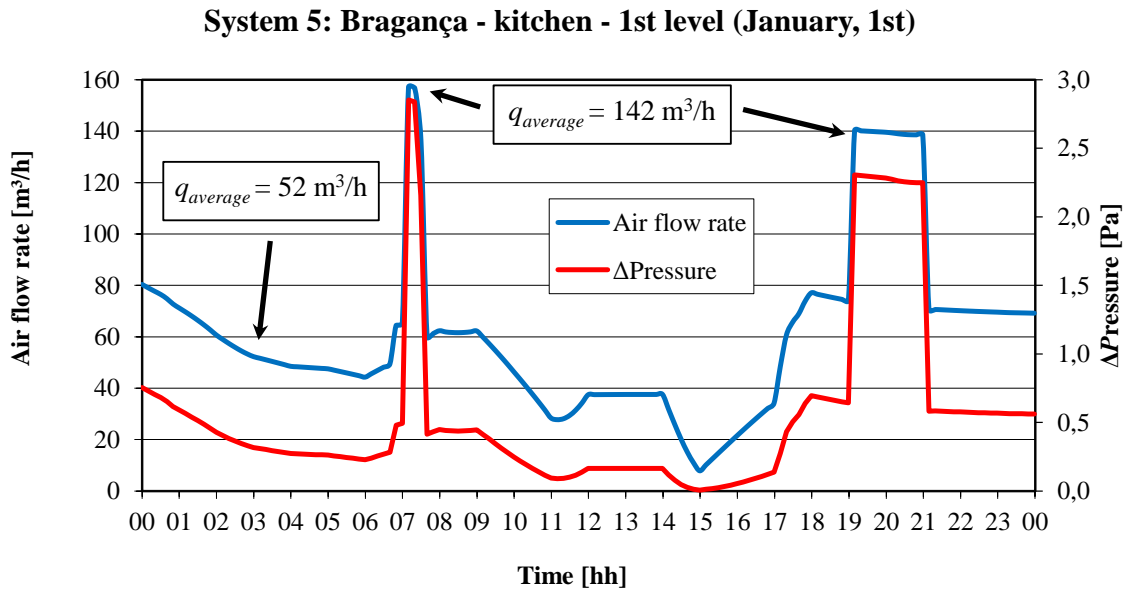


Figure 6. Ventilation system 5: Bragança, kitchen, 1st level - Relationship pressure-air flow rate in the inlet (1st of January)

4. CONCLUSIONS

The main conclusions to be drawn from simulations relevant to the design of a mixed system of ventilation in residential buildings are:

- Intake air flow rates, in relation to the recommended in NP 1037-2 [4], should be increased depending on the local wind regime (direction and speed);
- In the current situation, the interior doors must be open; in the event of strong winds that cause inner discomfort, they should be closed;
- In order to reconcile energy efficiency and indoor air quality, should be preferred to have an air inlet in the kitchen only when operating the mechanical extraction in this compartment;
- With the exception of the systems 5 and 6, the studied systems do not reach the minimum *ACH* stipulated in Portuguese legislation. In specific situations, the IAQ in the service compartments is quite poor. However, it was intended to find a scheme that ensures better ventilation conditions than currently practiced in buildings and currents with minimum resources.

For better performance of the systems the following recommendations should additionally be taken into account [10]:

- The air permeability of the windows should be reduced, thus avoiding the undesirable air flow rates which can influence the dynamics of the mixed ventilation system. The air permeability of the outer windows frames must then be limited according to the Portuguese standards, preferably to class 4 [11];
- The kitchen door should have low air permeability performance, according to the definition of the NP 1037-1 [3]; thus, a reduction of ventilation flow rate is obtained when windows are closed and in strong wind situations; similarly, the main entrance door must also have low air permeability performance;
- It is recommended that the doors of bedrooms, living rooms and toilet facilities are of high air permeability with bottom gaps of around 0.004 m² in order to not restrict indoor air flow;
- If necessary, additional horizontal ducts to facilitate the balance of air flow rates should be adopted, connecting the internal circulation areas (hall, corridor, etc.) and the openings located in the exterior walls (balance between two opposite facades); these "flow balancing" ducts must have a pressure drop equivalent to the pressure loss of the flow passing in parallel.

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