The influence of ventilation in the work of domestic combustion appliances

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SUMMARY

In dwellings with collective ventilation systems users often install mechanical exhaust hoods in order to improve the exhaust flow rate. In this research the impact of such devices on the work of the gas water-heater appliance (usually installed in the kitchen) is assessed. Field testing was carried out in order to evaluate the performance of natural ventilation systems in a multi-storey building and its adequacy to provide conditions for the work of the gas water-heater. The combination of mechanical ventilation in hoods and natural exhaust of combustion products of gas water-heater was also tested and critical conditions that lead to the safety stop of the gas water-heater were evaluated. A computer simulation program was used to predict the occurrence of safety problems in the work of the gas water-heater with different mechanical exhaust rates and two different air permeability of the building envelope. It is shown that it is possible to reduce negative impact of mechanical devices increasing the envelope air permeability, but this action will largely increase building heat loss.

INTRODUCTION

The use of domestic combustion appliances may cause the reduction of indoor air quality, due to the lack of outside air to feed the clean combustion or to deficiencies in the exhaust of combustion products. The contamination of indoor air may occur even when the exhaust of combustion products is made through ducts, when the domestic appliance is using the indoor air to feed the combustion, if the indoor pressure is lower than the pressure in exhaust ducts. Moreover, the progressive contamination of the indoor air, when a significant level of pollutants is reached, leads to a less efficient combustion that releases more toxic combustion products, namely CO. If the combustion appliances are equipped with safety devices, when the conditions that lead to the contamination of indoor air are detected the gas supply is cut and the appliance is stopped. In this case the safety is insured but the availability of the appliance may be quite low.

In naturally ventilated dwellings such an unfavourable difference of pressure between inside and outside may occur due to wind effect, but is more likely to occur due to improper use of mechanical extraction devices installed by the users after the construction of the dwelling disregarding the natural ventilation requirements.

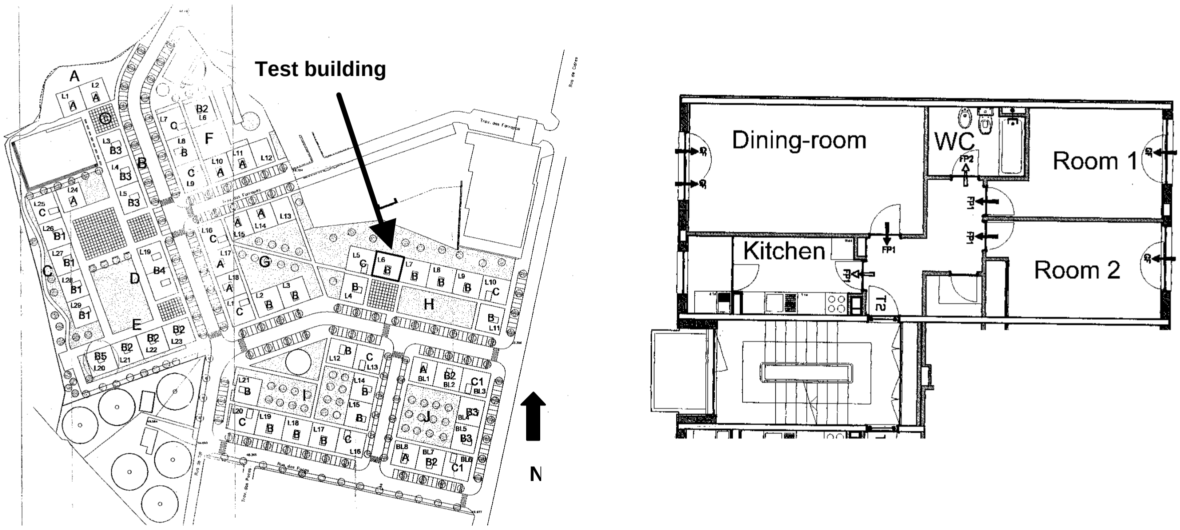
In the aim of two recent research projects (later referred as “Matosinhos research project” and “Gondomar research project”) it was possible to evaluate the performance of the combustion products exhaust in a naturally ventilated dwelling and in a mechanically ventilated dwelling. The characteristics of these buildings are detailed in following sections. Experimental results (duct flow velocities and temperatures and flow rate estimation) showing the adequate behaviour of both ventilation modes, providing good combustion products exhaust, were obtained. Besides, the problems that may occur due to inappropriate performance of these ventilation modes were also shown. In particular, it was possible to assess the problems that may be caused when the natural exhaust of combustion products from gas water-heater (GWH) is coexisting with mechanical ventilation of the kitchen (or WC) where the gas appliance is located. The ventilation modes that will provide adequate ventilation of combustion products are discussed and their impact in energy conservation is analysed.

A computer program, validated for the test case of Matosinhos research project, carries out the prediction of the performance of the ventilation of an apartment. The natural ventilation duct of the kitchen is common to kitchens in other apartments in the same building, so the behaviour of ventilation is strongly influenced by the pressures applied in other apartments.

METHODS

Design of natural ventilation of Matosinhos apartment

Testing was carried out in an apartment located in a 3-storey building (with 2 apartments in every floor). The ventilation system (fig. 1 b) is designed for nominal admission rates of 30m³/h in bedrooms and 60m³/h in dining-room and nominal exhaust rates of 45m³/h in bathroom and 90m³/h in kitchen. The flow rates are supposed to be balanced by air permeability of envelope.



a) b)

Figure 1. Plan of the neighbourhood (a) and sketch of test apartment (b) of Matosinhos

The exhaust ducts are: a ∅0,125 m individual plastic pipe located in bathroom and a duct in kitchen built with concrete blocks. Concrete blocks form a collective duct (725 cm² cross section area) serving the three kitchens on the same vertical and the outlet of every kitchen is connected to the collective duct by an individual branch (375 cm² cross section area and 1 storey high). Inside the apartment, gaps bellow the internal doors were left to allow the air to flow between compartments (140 cm² in the bathroom door and 200 cm² in the remaining doors).

The kitchen was equipped with a gas cooker and a GWH (the gas power was 19,6 kW for the gas water-heater and 22,7 kW when it is working together with the gas cooker). Weather conditions were assessed through a weather station installed on roof. Table 1 refers to measurements accuracy and table 2 refers to air permeability of the part of the envelope corresponding to every room ($\dot{Q}$ is the flow rate in m^3/h and ΔP is the pressure difference in Pa). Further test results may be found in [1] and [2].

Table 1. Measurements accuracy

Temperature in ducts	± 1,8 K
Flow rate in kitchen duct	± 21,0 m³/h
Flow rate in WC duct	± 4,2 m³/h
Temperature in rooms	± 0,6 K

Table 2. Air permeability of envelope

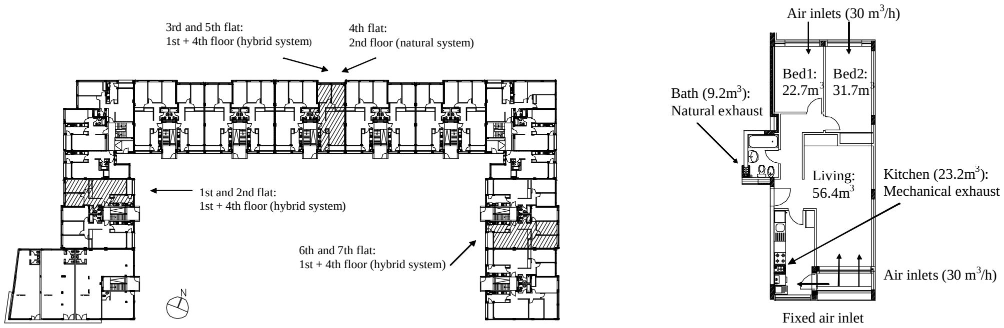
Room A	$\dot{Q} = 46.07\Delta P^{0.55}$ m^3/h
Room B	$\dot{Q} = 41.94\Delta P^{0.44}$ m^3/h
Dining-room	$\dot{Q} = 24.31\Delta P^{0.76}$ m^3/h
Kitchen	$\dot{Q} = 15.42\Delta P^{0.89}$ m^3/h

Design of mechanical ventilation of Gondomar apartment

Every apartment (except the kitchen) is provided with air inlets placed according to fig. 2, applied above the window. There is natural exhaust in WC through an individual plastic pipe of ∅110 mm with insulation and a static ventilator on the top. In the kitchen the exhaust from type A gas appliance (gas cooker) was made through a ∅150 mm individual metallic pipe and it was possible to vary the mechanical extraction up to 500 m^3/h. The natural exhaust from the GWH, located also in the kitchen, is made through a collective duct (serving three kitchens on the same vertical) ∅175 mm. The air permeability of the kitchen window is $\dot{Q} = 0.392\Delta P^{0,85}$ [m^3/h], according to laboratory measurements. The kitchen air inlet was applied on the internal door (the air permeability is $\dot{Q} = 76.7\Delta P^{0,5}$ m^3/h). More detailed description of the building envelope may be found in [3] and [4]. The accuracy of the measurements is similar to the one of Matosinhos measurements (table 1).

Simulation program

The simulation program is based on the computation of mass flow rate balance through all openings (ducts, air inlets, windows and doors), of head losses in ducts (individual and collective) using generalized Bernoulli equation and of energy balance in every duct. A set of routines adjusts the mass balance varying the admission pressure in every duct. Another routine correct the internal pressure of every apartment in order to comply with the mass balance, considering air inlets and outlets. In these routines the solution is approached by Newton Method. The procedure is carried out iteratively until the mass balance, in every routine, is satisfied for the same set of local pressures. An example of validation for flow rate from kitchen and from WC is shown in figure 5 [6].



a) b)

Figure 2. Plan of the neighbourhood (a) and sketch of test apartment (b) of Gondomar

RESULTS AND DISCUSSION

Gondomar case study: mechanical ventilation of hood

Tests carried out in Gondomar showed the activation of the safety device of GWH. In these tests the mechanical exhaust from the gas cooker in the kitchen of level 0 was activated with an increasing exhaust flow rate (up to 240 m³/h) while the GWH, installed in the same kitchen, was also activated. In the figure 3 a) the temperature curve measured in the exhaust duct of the water heater appliance is presented (ESQRCT). GWH was activated at 12:33 and the temperature quickly reaches about 60ºC. The flow rate measured at level 0 in the exhaust duct of the GWH (ESQRCV) is showed, in the figure 3 b), to increase up to about 80 m³/h. The flow rate measured in the same duct but above the level 2 (ESQ2AV) is also presented. This flow rate is higher than the flow rate measured at level 0 due to the entrainment of fresh air through the openings of the levels 1 and 2 kitchens. Mechanical exhaust from the level 0 gas cooker (FOGRCV in figure 3 a) is activated at 12:38 (to 20 m³/h). The mechanical exhaust from the level 0 gas cooker is increased at 12:43 (to 50 m³/h) and 12:47 (to 110 m³/h). Correspondingly the exhaust flow rate from the water heater appliance decreased to 65 m³/h and to 50 m³/h. Later, at 12:57 there is no more adequate conditions for the safe work of the GWH, the safety device is automatically engaged and the gas feeding is stopped. It is possible to notice that the temperature decay and the flow rate in GWH duct decay also.

These tests show that in this ventilation configuration (without direct ventilation opening between kitchen and outside) it is possible to induce to the GWH a safety stop with a rather low extraction flow rate from kitchen (only about 120 m³/h). The flow rate in the GWH before stopping was 40 m³/h (after 2 minutes of work with such a lower flow rate for a 20 kW gas appliance). This effect confirms that is undesirable the combination of natural and mechanical exhaust from the same space and that, in this case, there is not a problem of safety due to the action of the safety device.

In another test, the gas water-heater was activated in level 1 kitchen and the mechanical exhaust from the level 0 kitchen was activated (at 16:48) with an increasing flow rate (fig. 4

b). The flow rates in the combustion exhaust duct from GWH measured at level 1 and at the level 2 are also shown. At 17:07, for mechanical exhaust flow rate of about 500 m³/h, the pressure inside level 0 kitchen is low enough to revert the combustion products flow from level 1 kitchen to level 0 kitchen. Therefore, the temperature (fig 4 a) inside product combustion exhaust duct at level 0 increased severely (up to about 55ºC).

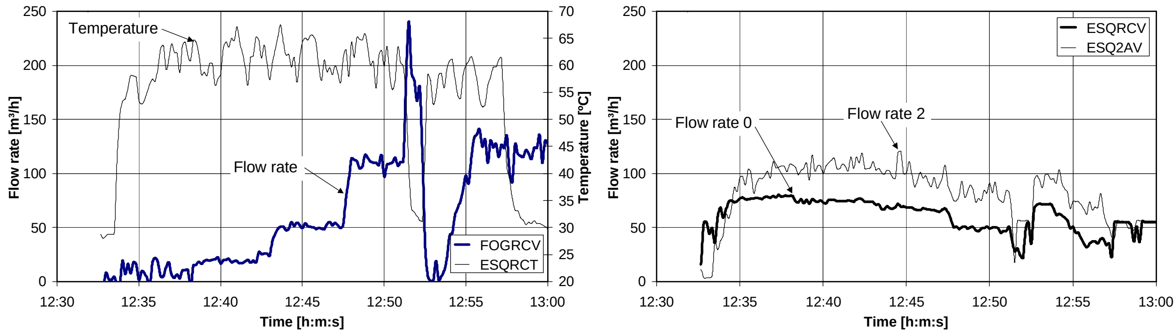


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Figure 3. Gondomar. Temperature and flow rates in kitchens. Activation of GWH in level 0.

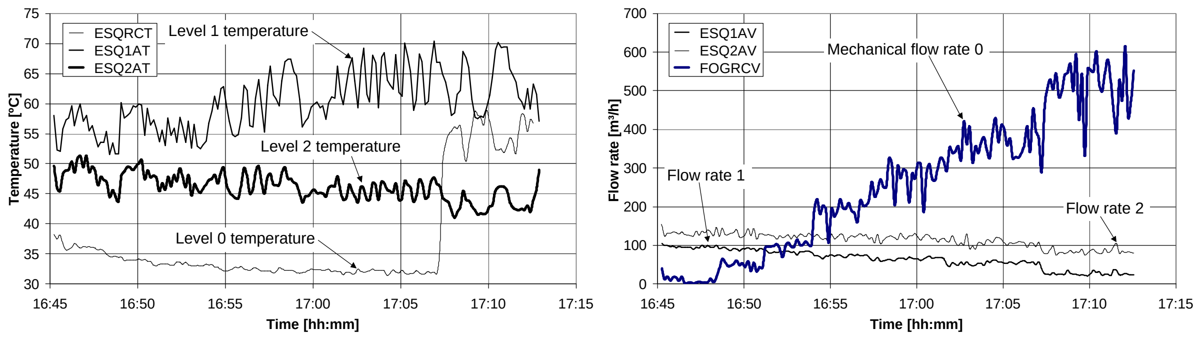

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Figure 4. Gondomar. Temperatures and flow rates in kitchens. Activation of GWH in level 1.

This test shows that the activation of mechanical ventilation in different apartments from those with natural ventilation (provided that they are interconnected by ducts) may create dangerous conditions due to reversion of combustion products flow. However, the level of mechanical exhaust flow rate is quite high (about 500 m³/h).

Matosinhos case study: natural ventilation

In Matosinhos tests it was possible to measure the natural ventilation performance in different seasons (February 2003, May 2003 and July 2003) with the occupants using the apartment [5]. In an initial period of testing (March 2001) the construction of the building was finished but there was no occupancy; therefore it was possible to control the state (opened or closed) of the openings in the envelope (mainly windows and doors) and to control the actions inside of testing apartment (space heating, use of combustion appliances). The characteristics of the envelope and the performance of the ventilation system were measured [1].

In figure 5 the measurements carried out during 2001 tests in Matosinhos show that the activation of the GWH (between 16:30 and 20:00) correspond to a temperature difference

$\Delta T \approx 45\,K$ and to a kitchen duct flow rate of about $\dot{Q} \approx 110\ m^3/h$. In figure 6 measurements of temperature of the room, exhaust temperature and exhaust flow rate for kitchen and WC in May 2003 tests are presented. In the kitchen exhaust temperature and kitchen exhaust flow rate there are two peaks (at 10:20 and at 11:50) corresponding to a temperature difference $\Delta T \approx 35\,K$ and to a maximum kitchen duct flow rate of $\dot{Q} \approx 125\ m^3/h$. The inside temperature of WC (and the corresponding exhaust flow temperature) is showing peaks at the same time, confirming that the occupants are using hot water in the WC that induced the activation of the GWH installed in kitchen. The temperature of the kitchen is not increasing, showing that the occupants do not use the kitchen and that there is no combustion products leakage to the kitchen. This shows that the exhaust of combustion products is made properly and that there is no risk to occupants.

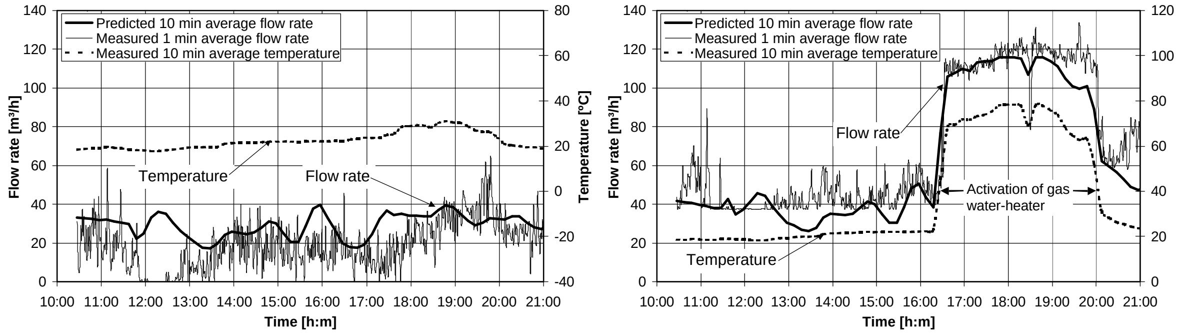

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Figure 5. Matosinhos. March 2001 temperature and flow rate (measured and estimated) in WC (a) and kitchen (b).

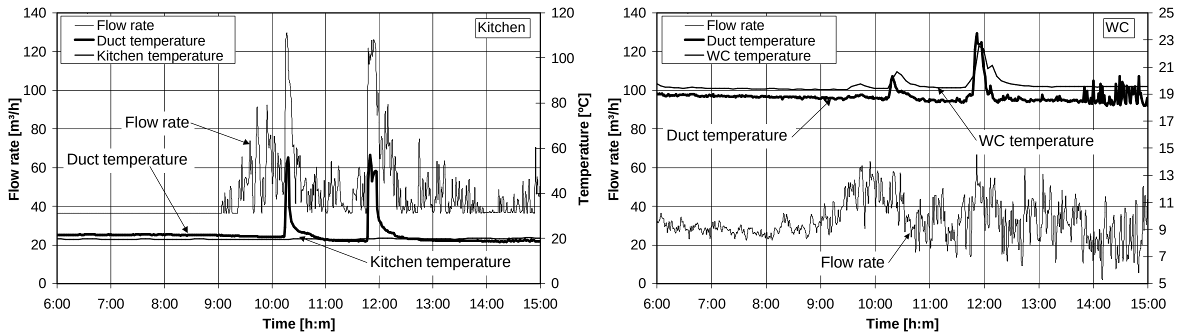

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Figure 6. Matosinhos. May 2003 temperature and flow rate in kitchen and WC.

In figure 7 the measurements of temperature of the room, exhaust temperature and exhaust flow rate for kitchen an WC in July 2003 tests are presented. To the temperature peaks in the exhaust flow from WC (at 12:30, 18:20 and 19:40, of 4th July, and 10:00 and 10:20, of 5th July) correspond similar peaks at the same time in the temperature and flow rate in the exhaust duct of the kitchen. These peaks should be interpreted as the activation of the GWH due to hot water consumption in the WC. These peaks correspond to a temperature difference $\Delta T \approx 35\,K$ and to a maximum kitchen duct flow rate of $\dot{Q} \approx 100\ m^3/h$. Again, no contamination of the kitchen with combustion products is indirectly perceived from the temperature measurements.

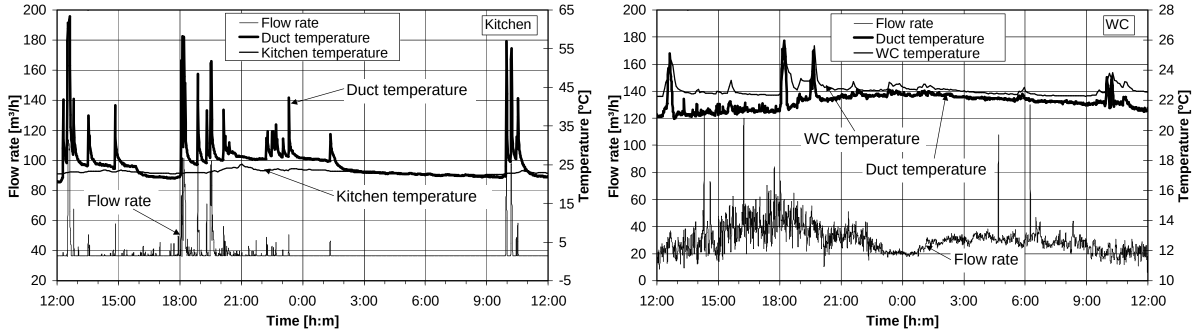

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Figure 7. Matosinhos. July 2003 temperature and flow rate in kitchen and WC.

In figure 8 the measurements of temperature of the room, exhaust temperature and exhaust flow rate for kitchen an WC in February 2003 tests are presented. In this case only the temperature peak in WC at 22:40 matches the temperature and flow rate peak measured in kitchen exhaust duct. The other peaks in kitchen exhaust flow rate and temperature correspond to the work of the gas cooker or, the highest peaks, to the consumption of hot water in kitchen. In this period, the temperature inside the kitchen shows a slight increment (at 19:15), that is certainly associated to the use of the of the gas cooker. The highest peak corresponds to a temperature difference $\Delta T \approx 30\,K$ and to a maximum kitchen duct flow rate of $\dot{Q} \approx 110\ m^3/h$.

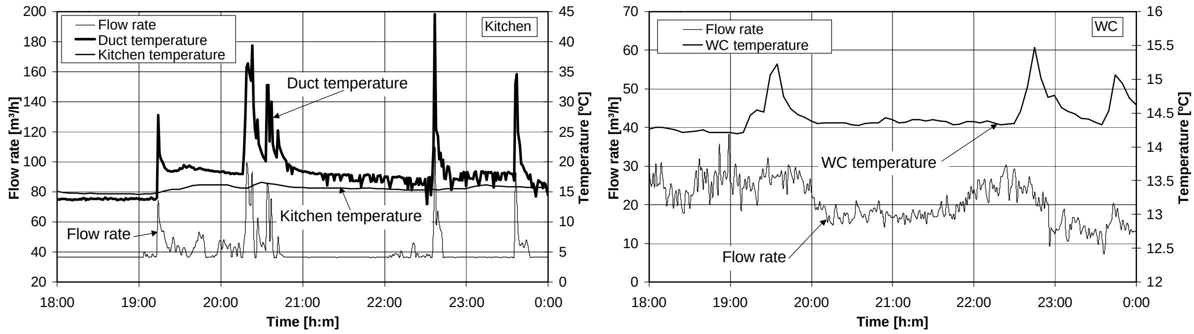

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Figure 8. Matosinhos. February 2003 temperature and flow rate in kitchen and WC.

The test results show that the GWH, with nominal power 20 kW, is loosing between 1.02 kW and 1.52 kW in the combustion products exhaust. This power is enough to provide a stack effect to avoid the pollution of indoor air with the combustion products in every season, but in the conditions of the air permeability of the envelope of the building and in these conditions of ventilation.

Simulation of different conditions for Matosinhos natural ventilation

Based on the computer code previously validated [6], the following different conditions applied to Matosinhos building were studied (figs. 9 and 10). The experimental data (weather and temperature data) used to run these simulations was the same used for the validation purposes (24 h from 10 am of 2001-03-07). In all predictions the external doors, opened during testing, were closed (kitchen of upper level and kitchen of lower level) and the flow meter installed in the WC of the intermediate level was taken out (the head loss in the duct was reduced in predictions).

a) *High air permeability* of the envelope; in this case the envelope data from Matosinhos building is kept;
b) *Low air permeability* of the envelope; in this case the envelope permeability is reduced to the Portuguese standard for natural ventilation NP 1037-1 [7] requirements, that corresponds to class 2 air permeability (according to EN 12207 [8]) of the windows (table 3) plus the air inlets;
c) *High air permeability* of the envelope, as in a) and mechanical extraction of the flow rate *500 m³/h* of the *lower* level *kitchen*;
d) *Low air permeability* of the envelope, as in b) and mechanical extraction of the flow rate *350 m³/h* of the *lower* level *kitchen*;
e) *High air permeability* of the envelope, as in a) and mechanical extraction of the flow rate *500 m³/h* of the *upper* level *kitchen*;
f) *Low air permeability* of the envelope, as in b) and mechanical extraction of the flow rate *500 m³/h* of the *upper* level *kitchen*;
g) *High air permeability* of the envelope, as in a) and mechanical extraction of the flow rate *200 m³/h* of the intermediate level *WC*;
h) *Low air permeability* of the envelope, as in b) and mechanical extraction of the flow rate *80 m³/h* of the intermediate level *WC*;

Table 3. Air permeability of envelope

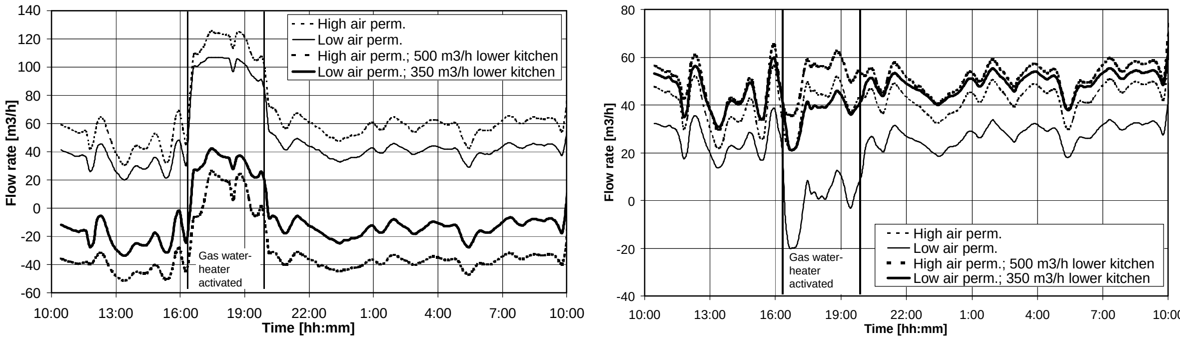
Room A and room B	$\dot{Q} = 2.92\Delta P^{0.67}\ m^3/h$
Dining-room	$\dot{Q} = 4.51\Delta P^{0.67}\ m^3/h$
Kitchen	$\dot{Q} = 1.67\Delta P^{0.67}\ m^3/h$

According to NP 1037-1 [7], the minimum flow rate required for the ventilation and combustion products exhaust of the gas water-heater is $\dot{Q} = 4.3 \times P$, being $\dot{Q}$ the minimum volume flow rate and P the nominal power. For a GWH of 20 kW, the minimum volume flow rate should be approximately 86 m³/h. The results show that the reduced air permeability of the building envelope should be compatible with the adequate combustion products exhaust from the GWH (fig. 9), because the flow rate is higher than 90 m³/h. When the GWH is not activated, the flow rate is about 40 m³/h, corresponding to approximately 2.0 ACH that is adequate when the kitchen is not in use. The flow rate in the intermediate level WC is in general adequate when WC is not in use (≈20 m³/h, that is about 2.0 ACH). However the heat source in kitchen will reduce the exhaust flow rate in WC to an unacceptable low level (even inducing flow reversal).

When the extraction of 500 m³/h is activated in the lower level kitchen (high air permeability envelope) it is pressurizing the common exhaust duct, therefore the exhaust flow rate from intermediate level kitchen is below the value of 40 m³/h, which was shown to lead to the safety stop of the GWH. When the GWH is not activated, the lower level extraction is blowing polluted air in the intermediate level kitchen, which is unacceptable. In consequence, the WC exhaust flow rate is increasing. It is shown that, when the air permeability of the building envelope is according to NP 1037-1, the exhaust of a flow rate of 350 m³/h in the lower level kitchen may lead to the safety stop of the GWH in the intermediate level kitchen.

When the extraction of 500 m³/h is activated in the upper level kitchen and the air permeability of the building envelope is high (fig. 10 a), the exhaust flow rate from intermediate level kitchen is close to the acceptable limit for the GWH work. When the air permeability of the envelope is lower it is not probable that a safety stop occurs. However, the flow rate may be most of the time, when the GWH is not activated, too low (about 20 m³/h or lower, corresponding to not more than 1.0 ACH).

The impact of the activation of mechanical extraction in WC (in the same apartment as the kitchen) depends, as expected, on the envelope air permeability (fig. 10 b). There is a small reduction (exhaust rate in kitchen not lower than 80 m³/h) when the air permeability is high and a stronger reduction (exhaust rate in kitchen between 40 m³/h and 65 m³/h) when the air permeability is according with NP 1037-1 [7]. It is supposed that the GWH is not affected by a safety stop; however, in the low air permeability case, it is expected that the combustion is affected by the reduction of the exhaust rate or that some releasing of combustion products to indoor environment may occur. Flow reversal in kitchen duct may occur when no heat sources are present in the kitchen, being more probable for low air permeability.



a) b)

Figure 9. Matosinhos predictions. Flow rate in kitchen (a) and WC (b).

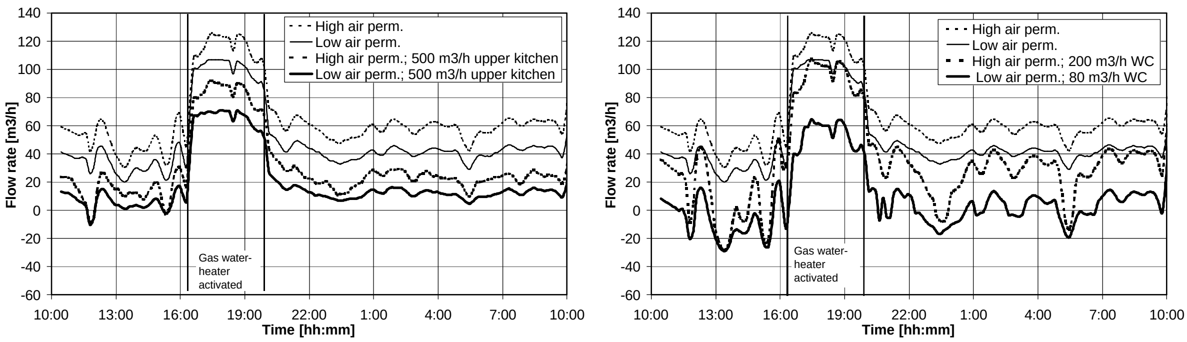


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Figure 10. Matosinhos predictions. Flow rate in kitchen.

CONCLUSIONS

Field testing on dwellings showed that natural ventilation is adequate to provide the air necessary for the safe work of GWH (that is usually the domestic gas appliance of highest power) and the exhaust of their combustion products. Field testing showed also that the combination of natural ventilation with mechanical ventilation in interconnected spaces may lead to dangerous situations of use of the GWH or, when it is equipped with a safety device, may lead to a safety stop (when combustion products exhaust flow rate is lower than 40 m³/h for a 20 kW nominal power gas appliance).

Very often, users may try to install local extraction fans in order to improve the existing natural ventilation system of their homes. Computer predictions showed that such action may have strong impact in the performance of the GWH in their own apartments and in the apartments served by the same collective natural ventilation exhaust, which may lead to a safety stop of the gas appliance. This impact is stronger for low permeability building envelopes and the activation of the mechanical extraction at a lower level kitchen has stronger impact for natural exhaust at an intermediate level kitchen than the activation of mechanical exhaust at an upper level kitchen. When the mechanical exhaust devices are installed in WC, the impact in the GWH (installed in the kitchen of the same apartment) work is lower because the air inlets of the apartment are able to compensate the lower pressure generated by the mechanical device; however, for high mechanical exhaust flow rates and low permeability building envelope cases a reduction of indoor air quality or a safety stop of the gas appliance may also arise.

The impact of the improper use of mechanical exhaust devices on natural ventilation systems may be reduced if the air permeability of the building envelope is incremented. However, this action will have a negative impact in energy conservation. The improper adoption of mechanical ventilation devices in such conditions should be avoided.

ACKNOWLEDGEMENT

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