FIELD CHARACTERIZATION OF THE ENVELOPE LEAKAGE OF HOUSES FOR DETERMINING REHABILITATION PRIORITIES

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ABSTRACT

This paper presents the results of a field study conducted on 8 houses (out of a set of 31) owned and managed by a French social housing public leasing company. The central objective of our investigation was to evaluate and characterize the envelope leakage of these houses in order to propose and prioritize rehabilitation scenarios. For this, envelope leakage measurements were performed together with infrared thermography measurements. In parallel, the occupants were interviewed to better understand their interaction with the thermal functions and what their feeling was about the thermal comfort and indoor quality in their homes. Also, heating energy use, as well as temperatures and humidities at several locations in the houses have been monitored during 63 days. Based on the analyses of the results of the measurements and interviews, actions including cost/benefit considerations have been proposed to the owner.

KEYWORDS

air leakage, envelope, survey, infrared thermography, thermal performance, low-income housing

INTRODUCTION

Envelope leakage has been studied for a number of years. Although there remain some questions and controversies about the energy impact of the presence of leakage paths through the building shell, there are a number of reasons why it may be desirable to minimize envelope leakage. In particular, leakage flows are uncontrolled that may cause uncomfortable cold draughts, or enhance cold wall effects. A secondary implication of deteriorated thermal comfort is increased energy use as the occupants may be lead to rise the set-point temperature to somehow counteract the leakage flows effects. The air quality may also be affected as the air passes through the cracks, potentially bringing more or less harmful pollutants indoors. Another important issue lies in water condensation that may appear for instance in winter conditions, either because of cold walls or because of exfiltration of hot humid air through insulating material.

Aware of those issues and aiming at maintaining its patrimony, a French social housing public leasing company (OPAC de l'Ain) decided to conduct a pilot field study with CETE de Lyon to evaluate the significance of envelope leakage of a group of 31 semi-detached electrically heated houses, to better understand its interactions with occupants' comfort and energy use, and to propose and conduct retrofitting actions. The last phase, which is now in progress, consists in evaluating the benefits of the retrofit on envelope leakage, occupant's comfort, and energy use. This work is part of a broader research program supported by ADEME and EDF that aims at evaluating the significance of envelope leakage and at improving the airtightness of new and existing buildings [1][2][3].

METHODS

Envelope leakage measurement. The envelope leakage of the houses was measured using the standard fan pressurization method according to ISO 9972 standard. The results are expressed in terms of a) the leakage flow coefficient (K in $m^3\ s^{-1}\ Pa^{-n}$) and exponent (n); b) in terms the leakage flow at 10 Pa in air changes per hour (τ_{10} in ach); c) in terms of the leakage flow at 4 Pa per unit area of exterior wall (I_4 in $m^3\ h^{-1}\ m^{-2}$). This last indicator is used in the new French thermal building code.

Infra-red thermography. Together with the envelope leakage measurement, we looked at window frames; electrical plugs (Figure 1), switches, and boards; exterior doors and access doors to attics; skirting boards; joints between walls, floors, and ceilings.

Temperature and humidity monitoring. Temperature and humidity loggers were installed in the kitchen, living room, and one bedroom. The outdoor temperature and humidity was measured simultaneously for a period of 63 days (609 degree-days (base 18°C)).

Heating energy use monitoring. During that same period, the heating energy use was measured. Note that all these houses have electrical heating with traditional resistance convectors; therefore, the heating energy use was monitored directly at the board.

Ventilation airflow rates. All houses are equipped with mechanical extract ventilation systems. Because the outcome of this study is to reduce envelope leakage, and therefore potentially reduce fresh airflow rates, the register airflow rates have been checked and a visual inspection was performed to identify defects such as voluntarily (or not) sealed ATD or insufficient door undercuts.

Questionnaires. We have conducted interviewed the occupants of the 9 houses that were monitored. The main points of interests were: a) the time-activity patterns, number of occupants and pets; b) general information on heating and ventilation including occupants' interactions with the thermal functions (equipment, window opening, etc.); c) occupants' opinions regarding the indoor climate and air quality.

FIELD STUDY RESULTS

The envelope leakage measurement results are synthesized in Table 1. The value of I_4 ranges between 0.6 and 1.6 $m^3\ h^{-1}\ m^{-2}$, with a median at 1.15 $m^3\ h^{-1}\ m^{-2}$. Except for one, the envelopes are considerably leakier than the reference used in the French building code (0.8 $m^3\ h^{-1}\ m^{-2}$). Thermography results have been added to this quantitative analysis to enable us to give a qualitative picture of the type and significance of leakage flows at specific locations in the houses. This information is condensed in Table 2. Consistently, considerable leakage was found the window frames, as well as at the access door to the attic. The identification of moderate or big leaks at most locations listed in Table 2 confirms that these locations are weak points with regard to envelope air tightness.

7 of the 9 interviewed occupants felt that their houses were rather cold, and one out of the two remaining had an additional heating device. 6 of them are not satisfied with the heating, and 7 claim there are uncomfortable cold airflows at the entrance door (3), at the garage door (3), at the “French” windows (3), at the electrical board (1). Globally, 4 persons are rather satisfied, although 2 among these note thermal problems, while 5 are dissatisfied. The dissatisfactions that arise are: cold feeling in winter time (5); lack of thermal insulation (5); presence of cold spots or cold airflows (3); poor heat distribution with the electrical heaters (1); the bad conservation of the buildings (1).

This information has been cross-examined with the temperature and humidity measurements. It is noteworthy that among the 7 occupants that complain about cold conditions, 4 of them have what is usually considered “comfortable” indoor air temperatures, or even high air temperatures (20 °C to 23 °C on daily average over the period of 63 days).

As for the heating energy use, it is found to range between 10.4 and 18.8 kWh per m^2 of floor area for 609 degree-days (base 18°C) for houses that did not use additional heating devices. (Table 3).

POTENTIAL IMPROVEMENTS

Retrofit actions have been derived for each type of defect, based on guidelines detailed in reference [1] and interactions with professionals. In order to be a decision tool useful for the owner, the actions have been prioritized (level 1 or 2, 1 is highest), with details concerning the work to be done (Table 4)

An economic evaluation of the retrofit has been made. The overall cost, including all actions, is estimated to be on average of 1300 Euros per house. Should the owner prefer to perform only priority 1 actions, the cost would be reduced to 900 Euros per house.

As for the ventilation systems, given their relatively good state, no specific retrofit actions were proposed apart from maintenance (clean and unblock if necessary ATDs).

CONCLUSIONS AND FUTURE WORK

The characterization of the envelope leakage enabled us to propose and prioritize retrofit actions. Based on the decision tool derived, the owner has chosen all of the priority 1 and most of the priority 2 actions to be undertaken (Table 4). First, the work will be done on 2 of the houses characterized, and a first evaluation will be performed. The feed-back of this first set of houses will be taken into account to adjust the rehabilitation scenario of the remaining 22 houses.

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REFERENCES

[1] EDF – CETE de Lyon. (2001). *Perméabilité à l'air des bâtiments d'habitation – Guide améliorer la performance des logements existants*. July 2001.

[2] Guillot, K., Litvak, A., Kilberger, M., Boze, D. (2000). *Ventilation performances in French dwellings: results from field observations and measurements*. UK, Air Infiltration and Ventilation Centre, proceedings of "Innovations in Ventilation Technology", 21st AIVC Annual Conference, held The Hague, Netherlands, 26-29 September 2000, paper 50.

[3] Litvak, A., Guillot, K., Kilberger, M., Boze, D. (2000). *Airtightness of French dwellings: results from field measurement studies*. UK, Air Infiltration and Ventilation Centre, proceedings of "Innovations in Ventilation Technology", 21st AIVC Annual Conference, held The Hague, Netherlands, 26-29 September 2000, paper 60.

Figure 1. Photograph with IR-camera of electrical plugs. The building was depressurized with a blower-door.

House ID	# 4 B	# 5 B	# 10 L	# 10 B	# 11 B	# 15 B	# 22 B	# 23 B	**Median**
Flow coefficient, *K* ($m^3\ s^{-1}\ Pa^{-n}$)	136.2	82.5	47.5	106	91.98	74.9	89.13	98.4	**90.55**
Flow exponent, *n* (-)	0.58	0.62	0.67	0.62	0.59	0.63	0.63	0.62	**0.62**
I_4 ($m^3\ h^{-1}\ m^{-2}$)	1.6	1.0	0.6	1.3	1.1	1.0	1.2	1.2	**1.15**
τ_{10} (ach)	1.9	1.3	0.9	1.9	1.5	1.2	1.4	1.5	**1.45**

Table 1. Envelope leakage measurement results.

House ID → Crack location ↓	# 4 B	# 5 B	# 10 L	# 10 B	# 11 B	# 15 B	# 22 B	# 23 B
Window frame - opening	⬛	⬛	⬛	⬛	⬛	▒	⬛	⬛
Window frame-wall	▒	▒	⬛	▒	▒	⬜	▒ other ⬛ louvre	▒
Main door (1) / garage door (2)	▒ (2)	▒ (2)	⬜ not measured	⬛ (1)	⬜ not measured	⬛ (2)	⬜ (2)	⬛ (2)
Electrical board	⬜ N/A	⬜ N/A	⬛	⬛	⬛	⬜ N/A	⬜ NA	⬜ NA
Electrical conduits	▒	⬛	⬛	⬛	⬛	▒	▒	▒
Vertical wall - slab	▒	▒	▒	▒	⬜	⬛	⬜	⬛
Access door to attic	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
Duct / pipe penetrations	⬜	▒	⬜	⬜	⬜	▒	⬜	⬛

⬜ no or few cracks

▒ small to medium cracks

⬛ large cracks

Table 2. Envelope leakage flow paths identified with IR thermography.

House ID	# 24	# 11	# 1	# 13	# 14	# 5	# 9	# 3	# 19	**Median**
Number of occupants	4	5	5	5	5	5	4	4	2	**5**
Additional heating device (yes/no)	no	no	no	no	no	yes	yes	yes	yes	/
Electricity energy use (kWh m^{-2}) for 609 degree-days	18.8	17.7	15.3	10.4	10.4	12.1	9.4	7.3	2.4	**of all : 10.4** **of "no additional heating de vice" : 15.3**
Mean indoor temperature in living room (°C)	21.2	23.2	20.5	19.1	20	20	20.9	17.4	19.6	**20**

Table 3. Energy use monitored on the 9 houses. The houses were monitored during 63 days (609 degree-days base 18 °C).

Type of defect	Priority	Actions
1. Windows		
1.1 Window frame - opening	1	- Replacement of the windows, except louvers. - For louvers, replacement of the weather stripping.
1.2 Window frame - wall	2	- Mastic joint between the frames (the existing frame is left in place). - Mastic joint around the window frame/wall before the new window is installed, inside and outside.
	1	- Louvers: mastic joint around the frame/wall interface.
2. Main door / garage door	1	- Replacement of undercut joint and joint around the opening. - Replacement of the garage lock.
3. Electricity		
3.1. Electrical board	1	- Injection of insulation foam to close the passageways to the air gap in the wall. - Removable caps at the end of the conduits.
3.2 Electrical conduits endings (plugs, switch, light fixtures, convectors)	1	- Mastic joint or insulation foam around the light fixture openings. - Insulation foam behind the plug boxes in cold walls. - Removable caps at the end of the conduits.
4. Vertical wall - slab	2	- Mastic joint around the vertical wall – slab interface, behind skirting boards.
5. Access door to attic	1	- Mastic joint around frame – ceiling. - Weather stripping around access panel – frame.
6. Pipe penetrations	2	- Mastic joints around conduits, at the penetrations.
7. Duct penetrations	2	- Insulation foam around the ducts at the penetrations in the attic, or - Joint around the duct / ATD connection to the wall.

Table 4. Summary of retrofit actions proposed to the owner.