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Field assessment of thermal behaviour of historical dwellings in France

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A B S T R A C T

In many countries, there is a great number of old buildings with local architectural, patrimonial, aesthetic and historic interest. They are the products of the vernacular traditional architecture fully integrating the environmental, social and economic local constraints.

Moreover, this built inheritance is more heterogeneous than the modern stock of existing buildings. The historical buildings were built with different architectural designs featuring local styles of construction, different techniques and historical expertise.

By experience, the actors of the building sector know that the thermal behaviour of historical buildings are not those of modern buildings set up at the time of the industrial period. However, they do not have assessed these specific thermal characteristics of historical buildings.

This paper describes the complexity of architectural designs of historical dwellings in France. A field investigation during one year highlights various thermal characteristics of 11 dwellings. It provides a new understanding of thermal behaviour of these historical dwellings. The results show the thermal characteristics of historical dwellings and their differences with modern architecture.

1. Introduction

The present energy and environmental constraints require the improvement of the energy performance and environmental quality of buildings. The European Energy Performance Building Directive requires extending thermal regulations to existing buildings and local specificities. The energy optimisation of existing building stock is a complex issue in many countries [1,2].

The existing building stock increases slowly. For instance, in France, there are more than 30 million dwellings with an average annual growth of 1–2% approximately. To reduce the CO_2 emission and energy consumption, the main effort must address this existing stock [1–4].

The energy performance of buildings is not the same for all the existing stock as shown in Table 1.

Three main periods of architectural design characterise the existing building stock. In many countries, the middle of the 20th century is a transition period that marks real changes in the constructive modes of residential buildings (Fig. 1). In France, more than 10 million of dwellings, a third of the existing building stock, were constructed before 1948 [6].

The elements that make it possible to carry out this constructive distinction are:

- new manufactured building materials that are easier to use (reinforced concrete floors, post-beams structures, concrete blocks) with hygrothermal properties that are different;
- constraints of town planning due to the real estate market that made it difficult to build in relation to the environment (orientations according to the sun and winds);
- economic and profitability constraints of the building sector related to a massive demand for dwellings after the World War II.

From the thermal point of view, there is an important change from an architecture taking into account the climatic environment and using local resources and materials, to an industrialised architecture, using new building materials with different thermal properties. At the same time, designers with new techniques available tend to ignore the local conditions of each site. The 20th century sees the beginning of the production of modern buildings: they are mechanically ventilated, heated and artificially lit.

The first international oil crisis and the first thermal building regulations also draw a line of essential fracture in the history of architecture. Since the 1970s, the requirements for the insulation of buildings are considerably reinforced and regularly updated.

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Table 1
Energy consumptions ratios in kWh/m^2 year of existing buildings in France [5].

Building sector	Use	Built before 1975	Built after 1975	Average
Residential	Heating	328	80–100	210
	Hot water	36	40	37.5
Tertiary	Heating	209	155	196
	Hot water	19	40	29

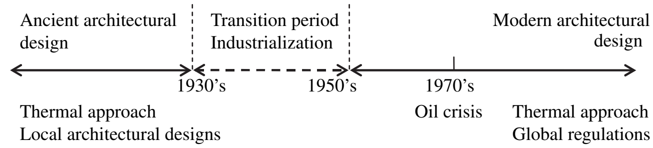

Fig. 1. Different thermal approaches and various architectural designs.

In this paper, a building is qualified as "historical" if built before the emergence of the modern architectural movement (before 1948). Thus, historical existing buildings constitute the inheritance and the identity of historic cities.

The history of architecture traces the changes in these buildings: a medieval period with a Romanesque and Gothic styles, a Renaissance architecture, a Baroque architecture, etc. For instance, during the Haussmann period in the 19th century, buildings complies with a set of rules regarding outside appearance. Neighbouring buildings have their floors at the same height and the use of quarry stone is mandatory along the avenues.

The historical buildings are constructed with traditional techniques and the historical expertise acquired by specialised building craftsmen. Professional practices were non-industrialised and there was significant interaction between trades. The knowledge of designers benefited from multidisciplinary experiments.

In this context, and from a heritage and architectural point of view, any energy retrofitting project of historical buildings is a risk in terms of sustainable development and a challenge in terms of the conservation of historical buildings [7–9].

2. Architectural characteristics of historical dwellings

The outdoor environment and the building site are influenced by the following constraints [10–12]:

- microclimate (wind, temperature, precipitation, exposure to sun, altitude, mountain or littoral area, urban or rural area, etc.)
- close relief (a cliff may moderate the changes in air temperature; an embankment slope may bring thermal attenuations, etc.)
- solar masks (other buildings, persistent vegetation, etc.)
- built-up areas and joint ownership

In a historical urban environment, the predominant urban form is a small urban block, which developed in the French cities under the Haussmann period. This urban form shows several characteristics having consequences on the energy performance and environmental quality of the building:

- built or vegetable masks: the planted drives (caducous foliage) of avenues limit the solar contribution in summer, particularly for the lower floors; they also reduce overheating of the roadway under trees.
- joint ownership of façades in most cases, which makes it possible to reduce thermal surface losses of an apartment.
- climatic variation between the street and the centre of the small urban block: these thermal differences (several degrees Celsius) are observed between the two façades of the building.

In rural areas, the situation of old buildings generally tends to optimise solar savings and to reduce thermal losses, featuring a main façade oriented to the south, few or no openings towards the north, use of vegetation to create shading in summer, etc.

The thermal behaviour of the building is generated by its situation and its architectural characteristics: orientation of rooms and spaces, distribution typology (crossing area or not), size of the rooms according to their use, etc.

For the historical buildings, without existing efficient heating, ventilation and air conditioning systems (HVAC), the indoor environment generally tends to conserve indoor comfort. Some characteristics of the indoor environment which influence the thermal behaviour are identified:

- Rooms distribution: there is a separation between living rooms and service rooms. These rooms tend to be set according to the sun path: living rooms on the sunnier side, and service rooms on the colder side.
- Thermal buffer spaces: back kitchens, cellars, storerooms and roofs are as many additional spaces, which constitute thermal attenuation zones limiting heat transfers with outside.
- Historical dwellings are designed with a crossing ventilation. Without HVAC equipment, the air ventilation strategy is a natural ventilation. Thus, a crossing dwelling makes it possible to create an effective airflow to improve the indoor air quality.

Historical buildings have different bioclimatic and vernacular characteristics. An example of bioclimatism and vernacular architecture is described in different climatic zones in north-east India [13]. The houses, with solar passive features in building design, are constructed using locally available materials. Another example

Table 2
Characteristics of historical dwellings.

N°	Location	Latitude	Longitude	Altitude	Architectural features	Date of construction
B1	Paris	48°87′N	2°33′E	34 m	Haussmann architecture, 5th floor, apartment	1918
B2	Strasbourg	48°33′N	7°38′E	153 m	Haussmann architecture, 1st floor, apartment	1898
B3	Toulouse	43°36′N	1°25′E	136 m	Brick architecture, 3rd floor, apartment	18th century
B4	Vouvray	48°17′N	1°38′E	142 m	Stone, lime mortar, Ground floor, apartment	1755
B5	Paris	48°87′N	2°33′E	34 m	Limestone, 1st floor, apartment	17th century
B6	Marne	49°05′N	3°95′E	74 m	Brick of clay, tile, House	1870
B7	Nice	43°95′N	6°90′E	450 m	Stone, lime mortar, tile, House	18th century
B8	Bretagne	47°90′N	3°27′W	96 m	Granite, stubble, House	17th century
B9	Corrèze	45°24′N	1°51′E	580 m	Granite, slate, House	15th century
B10	Normandie	49°42′N	0°45′E	20 m	Timber, cob, stubble, House	1789
B11	Alsace	48°82′N	7°73′E	150 m	Concrete, tile, insulation, House	2004