Thermal Behaviour of Traditional Architecture in the City of Florina in North-Western Greece

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ABSTRACT: The main goal of this paper is to explore the thermal behaviour of traditional buildings of the 19th century in the city of Florina, in North-western Greece, and to investigate the degree of thermal comfort of the users. For this purpose, it is necessary to analyse the climate of Florina, the construction methods and the building materials, as well as the patterns of use of the different spaces. In most cases, the ground floor contains the winter rooms, while the upper storey is used as the summer living space. This fact is intensely reflected in the construction of the house. The ground floor is built as a heavy structure with thick stone (or adobe) walls and small openings. At the same time, light timber-framed walls filled with adobe, construct the upper storey, giving the freedom for large windows and cross ventilation in the summer rooms and in the common spaces. The thermal behaviour of a typical traditional building of Florina is analysed with the calculation of the thermophysical properties of the different building elements, and with the use of thermal analysis software.

Conference Topic: 8 Traditional solutions in sustainable perspective
Keywords: traditional architecture, NW Greece, construction methods, thermal performance

INTRODUCTION

The vernacular architecture of every area is based on the accumulated experience and practice of many centuries and can constitute a continuous source of knowledge. The use of local materials and the harmonisation with the local environment and climate are some of the factors, which contribute to the distinct architectural identity of every area.

2. CLIMATE OF THE CITY OF FLORINA

2.1 Topography

The city of Florina lies in a mountain valley, which is crossed by a river from West to East. The longitude of the city is 21°23′59″, the latitude is 40°46′58″, and the altitude is 662 m.

2.2 Climatic Data

The mesoclimate of the area is affected by the presence of large mountainous volumes. The prefecture of Florina has a cold continental climate, with long, cold, humid winters and short, warm, and dry summers.

The mean maximum temperature in January (coldest month of the year) reaches 4.6 degrees C, the average temperature is 0.5 degrees C, while the mean minimum temperature is -3.5 degrees C. The mean maximum temperature in July (hottest month of the year) reaches 28.8 degrees C, the average temperature is 23.1 degrees C, while the mean minimum temperature is 14.4 degrees C. The corresponding relative humidity values are 82.1 % for January and 57.4 % for January (Table I).

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Min Temp (C)</td>
<td>-3.5</td>
<td>-1.7</td>
<td>1.3</td>
<td>5.1</td>
<td>9.2</td>
<td>12.5</td>
</tr>
<tr>
<td>Average Temp (C)</td>
<td>0.5</td>
<td>2.7</td>
<td>6.7</td>
<td>11.6</td>
<td>16.8</td>
<td>21</td>
</tr>
<tr>
<td>Mean Max Temp (C)</td>
<td>4.6</td>
<td>7.3</td>
<td>11.8</td>
<td>16.7</td>
<td>22</td>
<td>26.2</td>
</tr>
<tr>
<td>Rel. Humidity (%)</td>
<td>82.1</td>
<td>78.1</td>
<td>70.9</td>
<td>64</td>
<td>63.4</td>
<td>59.8</td>
</tr>
<tr>
<td>Aver. Rainfall</td>
<td>57.6</td>
<td>52.3</td>
<td>57.9</td>
<td>57.9</td>
<td>58.9</td>
<td>37.3</td>
</tr>
<tr>
<td>Days of Rain</td>
<td>12</td>
<td>12</td>
<td>12.3</td>
<td>11.3</td>
<td>11.2</td>
<td>7.4</td>
</tr>
<tr>
<td>Wind Direction</td>
<td>W</td>
<td>N</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>2.5</td>
<td>3.3</td>
<td>4.1</td>
<td>4.6</td>
<td>4.8</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Florina has relatively high precipitation values, with a monthly average value of approximately 55 mm. Also, the area is characterised by an extended
snowing period, which starts from November and ends in April. The direction of the prevailing winds is either west or north, depending on the seasons.

Figure 1: Monthly air temperature and relative humidity values. [1]

2.3 Climatic Analysis - Classification
The climate classification for Florina was defined using the software Meteonorm v4.0 [2] to generate hourly climatic data, which were then imported to the software Weather Tool v1.10 [3]. The psychrometric chart generated with the Weather Tool, for the whole year for Florina, demonstrates that climatic conditions are way beyond thermal comfort throughout the winter period (November to March) (see Fig. 2 and3). During the months October and April, the climate is rather cool, while from May to September the climate is moderate to warm-dry (August).

Figure 2: Monthly diurnal average temperature values plotted against thermal neutrality zone for Florina. [3]

Figure 3: Psychrometric chart for Florina. [3]

3. ANALYSIS OF BUILDING CONSTRUCTION OF TRADITIONAL BUILDINGS

3.1 Construction Elements
The construction of the house is made in the following way (Fig. 4): the upper part of the foundation walls is formed with the placement of wooden beams 8 x 8 cm on the inner and on the outer side. Afterwards, beams with dimensions 8 x 13 cm are placed every 50 cm upon the foundation walls and always breadthwise. These beams support the floor of the ground floor.

The structural elements of the ground floor are usually walls made of local stone or adobe bricks. These walls are 60 to 65 cm thick, and have an average height of 240 cm. Every 80 cm (distance equal to one third of the total height of the ground floor wall) horizontal wooden beams are inserted. The openings are constructed in a slightly different way: the lower part of the window begins at 60 cm from the floor and the total height of the window is equal to 120 cm, thus giving a different division of the total wall height. In many cases, vertical beams are also integrated in the structure, thus forming a frame-like wooden substructure. All the horizontal and vertical parts of the substructure are interconnected. Beams with dimensions 8 x 13 cm are placed every 50 cm upon the ground floor walls and always breadthwise. These beams support the floor of the upper level.

Figure 4: Typical wall configurations.

The structural elements of the upper floor are usually light-weight walls called tsatmas. These walls are 20 to 25 cm thick, and are formed by a wooden frame structure, which is filled up with adobe bricks, or, in some cases, small stones and mud. The wooden frame structure comprises of horizontal, vertical and diagonal beams, with dimensions 8 x 8 cm or 10 x 10 cm. The vertical beams are not placed in equal distances, but depend on the existence of openings in the wall. The horizontal beams are placed between the vertical ones, in a way similar to the ground floor structure (every 60 to 80 cm, depending on the existence of openings). Furthermore, diagonal beams are placed in the frames, thus giving the structure rigidity. Finally, the remaining voids are filled up with adobe bricks. The external and internal renderings of the ground and upper floor walls consist
of two layers. The inner one is a mixture of clay mud and straw, while the outer is lime-plaster.

The construction of the roof is made in the following way (Fig. 5): beams with dimensions 8 x 13 cm (grenties) are placed every 50 cm upon the upper floor walls. Above the partition walls, wooden trusses are constructed with vertical (orthostates or babades) and diagonal (ameivontes or tsimpidia) beams of 10 x 10 cm. These trusses support horizontal elements 13 x 8 (tegides) placed every 120 cm. Afterwards, diagonal elements 8 x 8 cm (epitegides or panotsimpida) are placed every 50 cm. These elements support the final layer of the roof, which comprises of wooden boards with a width of 10 to 15 cm, and clay tiles anchored with mud.

![Figure 5: Typical roof axonometric section.](image)

### 3.2 Building Materials

The materials, which were used for every part of the structure, came from the surrounding area. The stone blocks, which were used, were made of limestone and/or slate, and came mainly from nearby quarries. In some cases, especially for the houses located on the south side of the city (mountainside), the stone blocks were made on the site, from the earth, which was dug out for the construction of the foundations and the basement. Finally, the structural wooden elements were made of local hardwood, i.e. beech and oak, which came from the nearby woods, while the rest of the wooden parts were made of local softwood, i.e. poplar and fir.

### 3.3 Thermal behaviour of construction elements

There are three main wall configurations found in traditional buildings of Florina: a thick stone wall, a thick adobe wall, and a lightweight wall (tsatmas). The thermal behaviour of these elements can be described by their thermophysical properties (see Table II). The U-value data was derived from [4], whereas the time lag values were calculated according to the Thermal Time Constant (TTC) formula cited by Givoni in [5].

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness (cm)</th>
<th>U-value (W/m2K)</th>
<th>Time lag (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone</td>
<td>60</td>
<td>2.35</td>
<td>61</td>
</tr>
<tr>
<td>Adobe</td>
<td>60</td>
<td>1.02</td>
<td>109</td>
</tr>
<tr>
<td>Tsatmas</td>
<td>20</td>
<td>2.24</td>
<td>14</td>
</tr>
</tbody>
</table>

It can be seen that the first two wall configurations are characterised by an increased thermal lag, whereas the third wall configuration has a relatively low time lag. The high thermal inertia wall types were mainly used in the ground floor, which was occupied during the cold period, whereas the lightweight wall type was used in the upper floor, which was occupied during the warm period.

### 4. THERMAL ANALYSIS USING SOFTWARE

#### 4.1 Thermal Modelling

The thermal analysis calculations were performed with the software Ecotect v5.2 [4]. First, the model of a representative building type was constructed. Second, the model was modified in order to represent three variations based on existing examples, with differences in the orientation, the openings and the wall configurations. These variations included a house with northern orientation, one with eastern orientation, and one with southern orientation, which are referred from now on as N House, E House and S House, respectively (Fig. 6-8).

![Figure 6: N House. Ground and upper floor plans.](image)

![Figure 7: E House. Ground and upper floor plans.](image)

![Figure 8: S House. Ground and upper floor plans.](image)

The thermal modelling was based on a series of assumptions. The ground and the upper floor were used inter-seasonally, while the different rooms of each level were used either throughout the day, or for specific hours during the morning. These diurnal and inter-seasonal differences in the use of the house were represented with different schedules. The winter comfort band was set at 16 to 26 degrees C, whereas the summer comfort band was set at 18 to 28 degrees C. The winter spaces (ground floor) were
assumed with no ventilation apart from the air infiltration, while the summer spaces (upper floor) had natural ventilation. The infiltration rate for all the zones of the building was set at 1 air change per hour.

4.2 Hourly Temperature Profiles

For the coldest day (January 26th), the main winter living spaces of the N House demonstrate a very slight diurnal variation and range between -2 and 0 degrees C, with outside temperatures below -12 degrees C. On the most overcast day (January 22nd), the exterior temperature is about -2 degrees C, while the interior temperatures of the two zones throughout the day are around 0 and 2 degrees C.

For the hottest day (August 25th), the exterior temperature ranges from 22 degrees C (early in the morning) to 34 degrees C (around noon). The summer living spaces of the N House are warmer in the morning and in the night (25 degrees C), but significantly fresher around noon (29 degrees C). On the brightest sunny day (July 20th), the outside air temperature ranges from 14 degrees C to 34 degrees C, whereas the interior air temperatures of the main living spaces range from 22 to 27 degrees C.

4.3 Fabric Gains and Losses

The fabric gains and losses of the different zones of the houses depend mainly on the construction materials of their external walls. In the cases of heavy-weight wall construction, i.e. thick stone walls, the fabric losses throughout the cold period are significantly reduced. This fact is mostly observed in the winter secondary rooms of all three houses, and in the main winter spaces of the N House. The fabric losses during the winter also depend on the window area. As a result, spaces with few and small openings, as is the case with the ground floor of the N House, demonstrate few fabric losses.

The fabric gains of the summer living spaces are similar for all three houses. The time lag of the walls is such that the maximum fabric gains during the summer occur in the evening. Considering the daily exterior temperatures fluctuation (10 to 15 degrees C), this fact is very desirable in order to have comfortable interior temperatures in the night.

The roof zone is characterised by extensive fabric losses during the winter and intermediate seasons and very high fabric gains in the noon and afternoon hours of the summer. (Fig. 11)
4.4 Direct and Indirect Solar Gains

The direct and indirect solar gains of the houses are mainly based on their orientation, and on the surface and orientation of their windows.

The N House has very few direct solar gains, due to the lack of southern windows, during the winter. This is reversed in the summer living spaces, where there are increased direct solar gains throughout the morning, especially in the north-eastern main living space.

For the winter, the living spaces of the E House have direct solar gains throughout the morning because of the eastern and southern openings (Fig. 12). For the summer and the intermediate seasons, the living spaces of the E House have increased direct solar gains from early in the morning until noon. This is due to the large number of windows facing east. The elevated sums of solar radiation contribute positively to the thermal comfort conditions during the intermediate seasons, but can lead to heat discomfort in the summer.

Figure 12: E House. Direct solar gains of winter space (side areas of graph). [4]

The S House has direct solar gains only around noon, during the winter, because of the southern windows. The roof eaves efficiently shade the southern openings of the summer living spaces. In this way, the direct solar gains are minimised (Fig. 13), during the summer, when they are not desirable.

Figure 13: S House. Direct solar gains in summer living spaces (central area of graph). [4]

4.5 Inter-Zonal Gains and Losses

The inter-zonal gains and losses of the upper floor for all three houses are governed by the thermal behaviour of the roof. As a result, during the cold and intermediate periods, all the rooms, which are adjacent to the roof, demonstrate thermal losses towards it. Of course, these rooms were rarely occupied during these periods. On the other hand, the thermal contribution of the roof in the summer was significant, and contributed to the thermal loads of the adjacent -upper storey- zones. Nevertheless, it is known that the efficient cross-ventilation and night ventilation of those spaces moderated this negative contribution.

5. THERMAL COMFORT

5.1 Simulated Thermal Comfort

The overall simulated thermal comfort was similar for all three houses. Thermal discomfort was calculated for monthly percentage of time and assumed that the buildings were free running.

For the winter, the ground floor main living spaces of the S House have the less hours of cold discomfort (50% to 60% of the time) (Fig. 14). This is mainly due to the direct solar gains from southern windows, and the absence of other openings. On the contrary, the ground floor areas of the N House and the E House are very cold. The cold discomfort in the E House is slightly worse, is due to the increased area of windows. On the other hand, the N House ground floor is very compact, with few openings.

Figure 14: Percentage of cold discomfort for the main winter living spaces of the S House. [4]

For the summer, the main spaces of the upper storey of the S House are warmer (hot discomfort for 80% of the time) than the corresponding spaces of the other two houses (hot discomfort for an average of 60% of the time). This is mainly due to the fact that the main living spaces of the N House face north, and have reduced thermal loads, while the E House has optimised cross-ventilation, due to the increased number of openings (Fig. 15).

Figure 15: Percentage of heat discomfort for the main summer living spaces of the E House (central area of graph). [4]
profiles
Coldest day
Most overcast day
Hottest day
Sunniest day

<table>
<thead>
<tr>
<th></th>
<th>T Outside (°C)</th>
<th>N House</th>
<th>E House</th>
<th>S House</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coldest day</td>
<td>-12</td>
<td>-2</td>
<td>-1.3</td>
<td>-2</td>
</tr>
<tr>
<td>Most overcast day</td>
<td>-2</td>
<td>0.2</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Hottest day</td>
<td>22-34</td>
<td>25-29</td>
<td>24-29</td>
<td>25-29</td>
</tr>
<tr>
<td>Sunniest day</td>
<td>14-34</td>
<td>22-27</td>
<td>22-27</td>
<td>22-27</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thermal comfort</th>
<th>N House (°C)</th>
<th>E House (°C)</th>
<th>S House (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold discomfort</td>
<td>40-70%</td>
<td>30-70%</td>
<td>45-60%</td>
</tr>
<tr>
<td>Hot discomfort</td>
<td>65-80%</td>
<td>65-80%</td>
<td>75-85%</td>
</tr>
</tbody>
</table>

5.2 Reported Actual Thermal Comfort

The actual thermal comfort of the people living in the 19th century is significantly different from the contemporary standards of thermal comfort. In order to understand the perception of thermal comfort 150 years from today, it is very important to point out again the diurnal use of the different rooms and the inter-seasonal use of the ground and the upper floor.

During the cold period, people lived almost entirely on the ground floor, which is characterised by heavy mass and reduced area of openings in order to maximise the time lag and minimise the thermal losses. The thermal comfort of the users depended also on factors, such as clothing and rudimentary active heating methods, such as fireplaces and braziers.

The social and economic conditions in Florina, at the time, enforced the use of heavy clothing inside the houses. During the winter, the casual clothes like coats, shirts, trousers, socks and hats, were made of wool. At the same time, the intense everyday activities in the intermediate seasons contributed to thermal comfort of the users.

As far as the active heating methods are concerned, it should be noted that the fireplaces are placed on the ground floor, and are usually integrated in the middle of the internal or the northern walls of the house. As a result, these walls have the same thickness (60-65 cm) both at the ground and at the upper floor, for construction and safety reasons. Usually, the internal walls, which accommodate the fireplaces, enclose a semi-open space (hayat). In many cases, the fireplaces do not face towards the living spaces, but towards the hayat. This was mainly due to the fact that in the older houses, many of the household activities, like cooking and drying of fruits and vegetables took place in the hayat, whereas the enclosed spaces were only used for light activities and sleeping. In some cases, fireplaces exist even in the secondary rooms of the upper floor. This is reasonable, if we take into account that the intermediate seasons in Florina are relatively cold, with a possibility of snow, even in May.

During the summer period, the household was moved to the upper storey, were the design of the rooms allowed the use of cross-ventilation in order to promote the natural cooling of the living spaces. The summer clothes were made of cotton, hemp and linen, and all the intense activities were transferred to the open air.

The cross-ventilation during the summer is achieved not only in the summer living spaces (odas) with the simultaneous opening of two or more windows, but also in the whole house. In order to do this, small openings are constructed in the upper part of the northern hayat wall. In this way, the staircase and the hayat space contribute to the night cooling of all the living spaces. Furthermore, the light-weight structure of the upper storey walls, and the extensive use of wood in the construction (floor, ceiling and closets) contribute to the quick rejection of heat during the night.

CONCLUSION

This first approach to the thermal analysis of the traditional buildings of Florina proves that the climate and the local environment drastically influenced vernacular design and construction methods. Therefore, it is an architecture, which can be regarded as highly sustainable and energy efficient. The construction and organisation of the living spaces according to their diurnal and inter-seasonal use, are two of the many features, which were pointed out in this paper.

Finally, this paper revealed the need for a more detailed thermal analysis of the thermal characteristics of traditional houses in Florina. It is imperative that the study should be extended to include more building types. Furthermore, it is strongly believed that in order to obtain a more representative and complete idea concerning the thermal behaviour of traditional architecture of Florina, in-situ measurements of dry-bulb temperature and relative humidity should be conducted in representative houses of the remaining building stock.

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REFERENCES