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Thermal and Fluid Dynamics Analysis of Hungarian Folk Heating Appliances

Zsuzsanna Nádasi-Antal
Óbuda University
Ybl Miklós Faculty of Architecture and Civil Engineering
Budapest, Hungary
atolzseig@gmail.com

Attila Kerekes PhD
Óbuda University
Ybl Miklós Faculty of Architecture and Civil Engineering
Budapest, Hungary
kerekes.attila@ybl.uni-obuda.hu

Gergely Domonkos Nagy PhD
Óbuda University
Ybl Miklós Faculty of Architecture and Civil Engineering
Budapest, Hungary
Nagy.Gergely@ybl.uni-obuda.hu

Abstract

Characteristic heating appliances of Hungarian architectural heritage, such as the tiled stove (cserépkályha), a pot-shaped tiled stove (bögrés szemeskályha), and the furnace (kemence), reflect not only architectural history aspects but also their thermal properties in their development and evolution. Since knowledge of these historical heating appliances is largely limited to literary and visual sources, their testing under operational conditions is generally not possible, even with reconstructions. Consequently, the analysis of their thermal and fluid dynamics behaviour is primarily accomplished using CFD simulation (Computational Fluid Dynamics). A previous on-site measurement provides a reliable basis for the simulation, during which the flue gas emissions and temperature data measured at 32 points of a wood-fired tiled stove were recorded. By using the measured firebox temperature curve as a reference, the validation of historical appliances with similar heating and cooling parameters allows for drawing conclusions about the reasons for their design, prevalence, and evolution. Furthermore, the study offers relevant lessons for the design and operation of 21st-century wood-fired appliances. This is particularly significant because in Hungary, biomass, primarily firewood, is the second most common household fuel source. It provides heating for approximately 1 million households, or 4 million people [3], with the majority concentrated in family homes.

Keywords— Hungarian folk architecture, traditional heating appliances, tile stove, pot-shaped tile stove, furnace, CFD simulation, thermal performance, biomass heating, wood-fired appliances, architectural heritage

I. Introduction

The distinctive heating appliances that are part of Hungarian architectural heritage, such as various types of furnaces (kemence), tiled stoves (cserépkályha), or the stove with mug-like tiles (bögrés szemeskályha), are significant not only from an architectural history, archaeological, or ethnographic research perspective; their thermal properties, among other factors, also played a role in their development and evolution. The purpose of this publication is to outline the developmental history of heating appliances used from the Middle Ages to the mid-20th century, to present their regional differences, while also analyzing their operation from a thermal and fluid dynamics standpoint. The investigation highlights that folk architectural forms are fundamentally determined by available resources, particularly fuel supply and climatic conditions.

II. Historical Overview, History of Development

A. Beginnings

The history of Hungarian heating appliances dates back to the pit-houses of the Hungarian Conquest era, where a corner-built furnace, heatable from inside the room, was typical. The 15th century brought a significant change in heating culture with the appearance of smoke-free residential houses. It was during this time that stoves heated from the outside became widespread in rooms, first among the aristocracy and later among the poorer classes as well. An early form of the stove was a further development of the traditional furnace, in which large, bowl- or pot-shaped ceramic elements, so-called "kályhák" (stove with pot-shaped tiles), were built into the thick adobe wall. The name for these structures that became common was bögreszemes kemence (furnace with pot-shaped tiles) or kályhás kemence (stove-like furnace).[9]

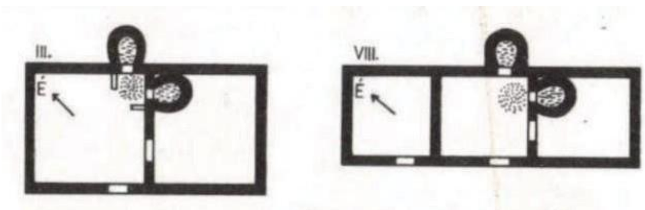
B. Tiled Stove

By the 15th century, for the most sophisticated constructions, the technology had undergone significant development. The body of the stove was now constructed from separate, thin ceramic elements—tiles—and plinths, central ledges, and the characteristic stove shoulder appeared. The most important thermal consequence of this structural change was the thinning of the stove wall. [7] Whereas the thick cob wall of earlier furnaces radiated heat slowly and for a long time, here only a single tile-thick ceramic layer separated the firebox from the room to be heated. These tiled stoves were typically built without a backing wall, which enabled much faster heat dissipation to their surroundings.

Tile stove, Southern Transdanubian type, Zselickisfalud, 1931 (Sabján, 2008, p. 64)[7]

C. Furnace

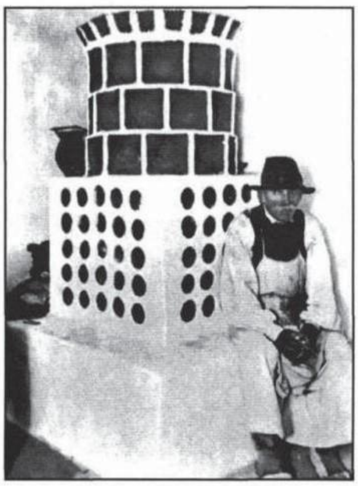
From the 15th-16th centuries, two distinct types of furnaces with different functions emerged: one for heating and one for baking-cooking. Several significant differences can be observed between the two functionally different types. Among the peasantry, the heating furnace in rooms were always furnaces with pot-shaped tiles, meaning their walls were lined with ceramic tiles. [9] It is not yet entirely clear why the use of furnaces with pot-shaped tiles on the Great Hungarian Plain during the 18th century and the more ornate oven was replaced by a simple furnace made of mud, but the reason may be poverty or a decline in the number of master potters. In contrast, ovens used for baking and cooking were never decorated or lined with "pot-shaped." Typical types of ovens used for baking-cooking purposes were the so-called projecting ovens, which protruded from the house's contour, and the so-called summer ovens, built outside the house and used—as their name suggests—during the summer period. [9]



House with projecting furnace [10]

D. Stove with pot-shaped tiles

The stove with pot-shaped tiles was also of medieval origin. In its structure, it represented a transition between ovens and tile stoves, combining the durable heat storage of thick-walled ovens with the rapid heat emission of thin-walled tile stoves. Its lower, square section was built from pot-shaped tiles set into thick, approximately 30 cm mud walls, while its upper, cylindrical part consisted of closely fitted, bowl-shaped ceramic tiles that were in direct contact with the firebox and were fixed together with mud mortar. The stove with pot-shaped tiles thus represents an indispensable stage in the development of Hungarian folk heating appliances. [5]

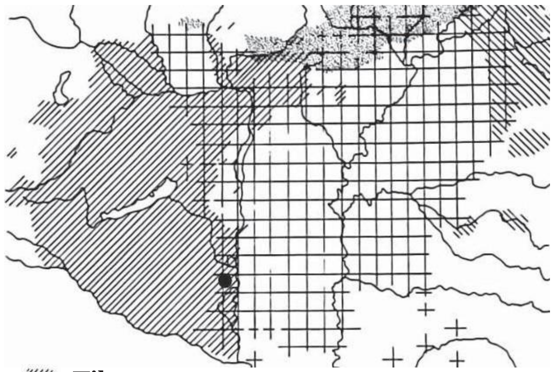


Sárköz stove with pot-shaped tiles, photograph by József Csalagovits, 1934 (Dr. Csalagovits, 1935) [3]

III. Geographical Distribution

By the 20th century, different types of heating appliances had developed distinct regional distributions, which were logically connected not only to building traditions and cultural influences but also to the available fuel. [7]

- In Transdanubia, tile stoves became widespread, where wood burning was dominant in the forested areas.
- In the timber-poor regions of the Great Hungarian Plain, burning straw and other agricultural by-products was available. Here, the externally fired oven became the typical heating appliance.
- The stove with pot-shaped tiles survived the longest at the border between the two major regions, in Decs along the Danube, where both wood and straw were available, thus representing a transition both geographically and functionally between ovens and tile stoves.



Tile stove
Externally furnace
Stove with pot-shaped tiles (Decs)

IV. Structural Analysis

The different functioning of various types is explained by their material and structural characteristics. The differing thermal properties of mud and ceramic tiles (thermal conductivity coefficient, thermal effusivity) fundamentally determine the behavior of structures built from them. [5]

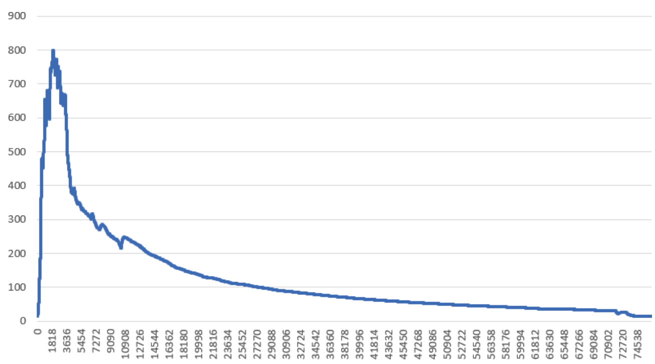
Material Characteristic	**Materials**	
	Mud	***Ceramic tile***
Density	900 kg/m³	2000-2400 kg/m³
Thermal conductivity coefficient (λ)	0,5-0,7 W/mK	1,0-1,3 W/mK
Heat storage capacity (Specific heat)	0,85-1,4 kJ/kgK	0,84-0,92 kJ/kgK
Volumetric heat storage capacity [kJ/(m³·K)]	891 [kJ/(m³·K)]	1936 [kJ/(m³·K)]
Thermal effusivity	543 J/(m²√s·K)	1900-2100 J/(m²√s·K)
Emissivity coefficient	0,91-0,93 (whitewashed wall) 0,85-0,90 (mud)	0,90-0,94 (glazed) 0,85-0,90 (unglazed)

IV. Investigation: CFD Simulation

Since knowledge of these historical heating appliances is largely limited to literary and visual sources, their examination under operational conditions—even in the case of reconstructions—is not generally possible. Therefore, the analysis of their thermal and flow behavior can primarily be achieved through the CFD (Computational Fluid Dynamics) simulation method.

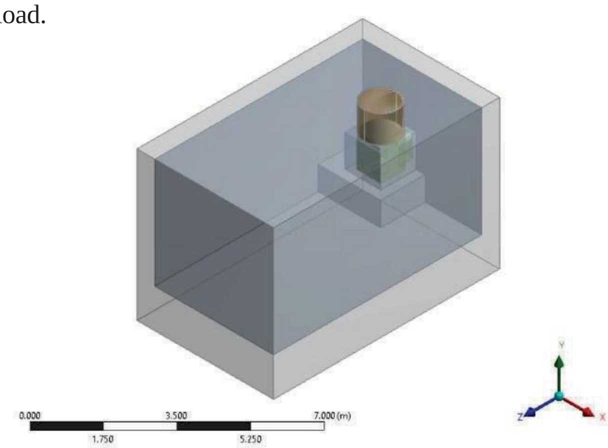
The simulation is based on an on-site measurement, during which the flue gas emissions and temperature data measured at 32 points of a wood-fired tile stove were recorded. By using the measured firebox temperature curve as a reference, through the examination of historical appliances with similar heating and cooling parameters, we can draw conclusions about the reasons for the emergence, survival, and development of these appliances. During the measurement, the volume flow rate was assumed to be constant throughout.

The measured firebox temperature curve used as the input boundary condition for the simulation. The data series shows the heating and cooling cycle of a real tiled stove, which served as a reference for modeling the behavior of the historical appliances. The maximum measured firebox temperature was ~800°C, and the measurement duration was ~75000 seconds (~21 hours)



Measured firebox temperature curve

Through the thorough examination of a single structure via the stove with pot-shaped tiles, we can gain insight into the essential differences between furnaces and tile stoves, as well as into the process of their developmental divergence. In the simulation, the model was created based on the geometry of the stove with pot-shaped tiles from Decs, but the pot-shaped tiles were not modeled separately in the wall of the lower prism. The investigation analyzes the response of the 30 cm thick mud wall and the tile-thickness ceramic wall to thermal load.

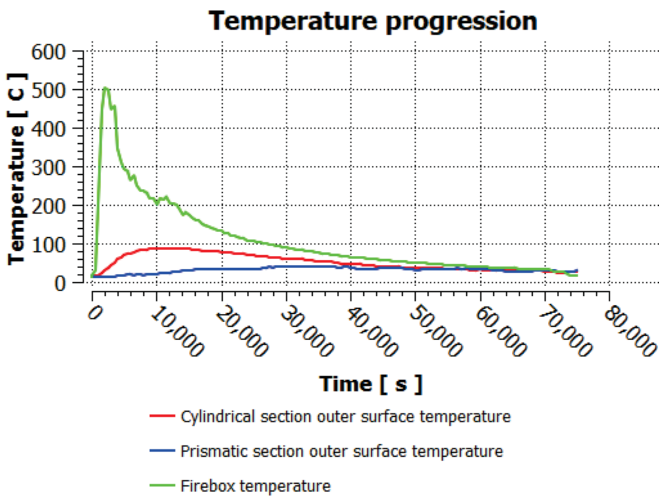


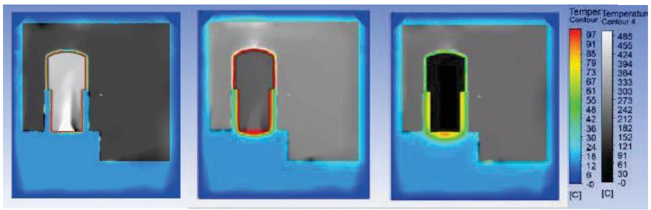
Geometry of the stove with pot-shaped tiles from Decs

The simulation was performed using Ansys CFX software. The computational mesh, created using the Hex dominant method, consisted of domains including the stove walls, the cylindrical upper section, the surrounding air, and the firebox. Heat transfer was described using the Thermal Energy model, and thermal radiation was described using the Monte Carlo method, taking into account 10,000 particle histories. For air, buoyancy was also modeled (Buoyant model). When determining the boundary conditions, the temperature curve from the previous on-site measurement was applied as a time-dependent function at the firebox inlet, with a constant inflow velocity of 1 m/s. The external boundary walls of the examined room were assumed to have a constant temperature of 0 °C, while the stove door was considered as a 15 °C opening.

The thermal effusivity of ceramic tile is approximately 3.5-4 times greater than that of mud, which means faster heat exchange and more dynamic behavior. The higher thermal effusivity ceramic surface reacts quickly to temperature changes, while the lower thermal effusivity mud results in slower, more balanced, and more comfortable heat sensation.

The temperature curves recorded during the examination of the stove with pot-shaped tiles clearly illustrate the dual operating principle of the structure. Following the rapid rise in firebox temperature, the upper, thinner-walled, cylindrical part consisting of ceramic tiles heats up almost immediately and provides rapid, intensive heat emission, similar to tile stoves. In contrast, the lower prism with thick (approximately 30 cm) mud walls absorbs heat significantly more slowly, and its surface temperature remains at a lower level. This massive lower part functions as a huge heat storage mass, which is capable of radiating uniform, comfortable heat to its surroundings for many hours (up to 18-20 hours) after firing has ended, similar to traditional furnaces. It can be seen that although the firebox temperature remains higher than that of the walls almost throughout, the stove walls begin to cool after approximately 10 hours, as the room air cools them to a greater extent.





Simulation results at maximum outer temperature values of temperature curves (at 1.500, 12.000, and 20.000 seconds)

In the simulation results displaying temperature distribution, the solid structural elements (stove and walls) are represented with a color scale, while the gaseous medium (air) is shown in a black-and-white scale. The color scale displays temperature values between 0-100 °C while the black-and-white scale covers a range of 0-500 °C.

The simulation results confirm that the stove with pot-shaped tiles combined the advantages of the two fundamental heating appliance types: the rapid heating capability of tile stoves and the long-lasting heat storage of furnaces. This structural solution enabled the efficient utilization of fuels with different combustion properties and represented an advanced heating technology perfectly adapted to environmental conditions, which is an outstanding example of Hungarian folk architecture.

V. Conclusions

The current simulation study confirmed the dual operating principle of the stove with pot-shaped tiles; however, further investigations are necessary for a more precise understanding of its heat emission. Future research should aim to quantify the ratio of heat dissipation between the two main parts of the stove body—the lower prism and the upper cylinder—throughout the entire heating cycle. It would be particularly important to analyze how the ratio of heat emitted through radiation and convection changes during the heating and cooling phases. With this data, we could gain a more accurate picture of the extent to which this advanced structure was capable of efficiently burning different types of fuel and dynamically regulating the comfort of the living space.

The spread of different heating appliance types was primarily determined by the nature of available fuel. Since the rapidly released, high heat energy of straw required the enormous heat storage mass of the furnace for absorption and slow release, which was ensured by the thickness of its walls varying between 20-30 cm, the more extreme temperature conditions of the firebox were better balanced. In contrast, for the slower, more evenly burning wood, the smaller mass of the tile stove was sufficient, which in turn provided faster heating, since only a single tile-thickness ceramic layer separated the firebox from the room to be heated.

The ceramic tiles built into the walls of early heating furnaces were not exclusively decorative. They increased the heating surface and, since they were in direct contact with the firebox, their warmer temperature significantly accelerated heat emission, which thus had practical significance only in the case of furnaces used for heating.

It has long been known that the type of heating appliances and their placement directly influenced the floor plan of folk houses. However, baking-cooking furnaces were connected to the peasant homestead's living space in a different way, because their primary role was heat retention, not heat emission. Since these were used in summer as well, the projecting furnace may have developed to avoid overheating, the great advantage of which was that from spring to autumn, that is, during the warm summer period, it reduced the heat emission of the stove body toward the living space. This same fact explains why summer furnaces were built separately from the house, as their name also reflects: when used in summer, they did not heat up the house during use.

VI. Results: Architectural and Social Implications

The results of the investigation go beyond technical-historical curiosities.

The investigation thus highlights that folk architectural forms were not created out of tradition preservation or primarily aesthetic considerations, but developed as a response to available resources (fuel, building materials, expertise) and climatic conditions (summer overheating). Regional differences therefore primarily reflect not cultural isolation, but adaptation and adjustment to the environment.

Based on data from the Hungarian Central Statistical Office, there are approximately 326,000 peasant houses, farmsteads, and other buildings with folk architectural value in Hungary, for which there is a prominent need to preserve the original character of buildings and carry out authentic renovations. This creates significant social demand for the dissemination and promotion of the application of traditional folk heating appliances.[4]

In addition to all this, the investigation also provides relevant lessons for the design and operation of 21st-century wood-fired appliances. This is of particular significance, since in Hungary biomass, primarily firewood, is the second most common household fuel among energy carriers. It provides heating for approximately 1 million households, that is, 4 million people [3], the majority of which is concentrated in the heating of family houses.

References

[1] Bátky, Z. (1903). Régi sárközi kemence. In V. Dr. Semayer, Néprajzi értesítő 4. (old.: 257-260). Budapest: Magyar Nemzeti Múzeum.

[2] Dr. Csalagovits, J. (1935). Népi építkezés emlíkei a tolnamegyei Sárközben. In L. Bartucz, Néprajzi értesítő 27. évf. (old.: 1-10). Budapest: Magyar Nemzeti Múzeum.

[3] Kármán-Tamus, Pálvölgyi (2022). A fenntartható energiagazdálkodás szociális dimenzió, Gazdálkodás, 324-341 p

[4] KSH (2016) Miben élünk? www.ksh.hu/docs/hun/xftp/idoszaki/pdf/miben_elunk15.pdf

[5] Libik A. (2013). Fatüzelésű épített kályhák. Budapest: Terc.

[6] Sabján, T. (2002). Bögrés szemeskályhák az Alföldön. In Gerencsérek, kályhások, tűzvigyázók Feudáliskori kályhacsempék az Alföldről és peremvidékéről. Gyula: Gyulai katalógusok 11.

[7] Sabján, T. (2008). Népi cserépkályhák (5. kiadás. kiad.). Budapest: Terc.

[8] Sabján, T. (2002). A búbos kemence (2. kiadás. kiad.). Budapest: Terc.

[9] Szabó, K. (1938). Az alföldi magyar nép művelődéstörténeti emlékei. Budapest: Országos Magyar Történeti Múzeum.

[10] Ortutay, G. (1980). Magyar néprajzi lexikon III. Középmagyar háztípus, Budapest: Akadémi Kiadó