INNOVATION AND RECEPTION HISTORIC HEATING SYSTEMS IN EUROPEAN MUSEUM ARCHITECTURE OF THE 1ST HALF OF THE 19TH CENTURY

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Keywords

History of services (heating) in buildings

Abstract

The first central heating systems were invented at the turn of the 19th century, predominantly for factory buildings and greenhouses. In the following five decades they developed from curiosities to an independent branch of industry and conquered the newly emerging architecture of administration, ecclesiastical, cultural and industry buildings. The main inventions and systems of the individual types of central heating from this period were named in general in older publications such as Vetters Bericht[1] as well as in the current publications written by E. Gallo[2] and C. Manfredi[3] and individual examples were described in more detail. A detailed treatment, comparing the individual central heating types in terms of construction, function principles, integration, dimensions and performance is lacking to date.

This paper outlines, how this ‘gap’ can be closed, by presenting in detail three selected central heating systems of one building type and comparing them with one another in accordance with the aforementioned criteria. The first independent European museum buildings are particularly appropriate for such a comparative treatment. A Europe-wide comparison furthermore facilitates a conclusion as to what extent the British technical innovations were absorbed or modified. The following representative heating systems are considered in this paper:

- The steam heating system in Dulwich Picture Gallery, near London (1812)
- The hot air heating system in the Alte Pinakothek in Munich (1822-36)
- The hot water heating system in Neues Museum in Berlin (1841-55).

Through these three buildings, a wide net is cast over the three main central heating types (steam, hot water and hot air heating) as well as the designated period (1st half of the 19th century).

The results indicate that one of the main driving forces of the industrial revolution, the steam engine, was also the breeding ground for central heating and that the scientific findings of thermodynamics were used for the dimensioning of the heating systems considerably earlier than previously assumed.

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PREMISE

In the wake of the industrial revolution and the shortage of wood fuel associated with it, a multitude of innovations in central heating technology were developed at the end of the 18th and beginning of the 19th century. While some, trusting in the experience of antique and mediaeval heating systems (hypocaust or stone oven heating systems), used air for heat transfer, others invested in more effective heat carriers such as water and steam. The key driving forces for this development were both the continuously growing need for greenhouses as well as the rapidly increasing number of factory buildings. While the former required an artificial climate that was as constant as possible for the cultivation of exotic plants, the latter required a safe, economic and easily operable temperature control for large production halls. New building typologies, emerging as a result of state and administration reforms and intentionally designed for large numbers of people, such as prisons, hospitals, banks and administration buildings, also required a central heating system for the heating of the indoor air, which has to be constantly renewed. Approximately by the mid 19th century, the evolution of the experimental heating system into an independent branch of industry had been accomplished Europe-wide.

But how were the individual central heating systems constructed and by whom, how did they function and how were they integrated into the relevant buildings? What do we know about the dimensions and actual performance of these systems? One of these new building typologies, the museum, appears to be particularly suitable for a detailed and comparative analysis of the individual central heating systems in terms of the above questions. Museums were built almost simultaneously in all large cities of Europe and the concept and structure of the buildings were very similar to one another. They were not committed to a ‘tradition’ and the almost identical technical requirements (fire and humidity protection for the works of art) generally called for the integration of a central heating system. As evidence for this hypothesis, one heating system of a representative museum building will be presented in the following for each of the heat carriers outlined above.

TYPOLOGY – CONSTRUCTION, FUNCTION AND INTEGRATION

The steam central heating using Dulwich Picture Gallery as an example

One of the first public museums, the single storey gallery building in Dulwich designed by Soane 1811-1812, was to be heated both by a modern central steam heating system as well as traditionally by local fireplaces. The main source of heat for the enfilade of five equally wide galleries with skylights was a central steam heating system. The system’s pipes were guided in brickwork ducts underneath the wooden flooring and the heat rose through floor grates at regular intervals. In addition to the central heating, Soane also installed a central, open fireplace in both of the long gallery rooms. The mausoleum, situated in the centre of the west side, was intentionally left unheated, in order to strengthen the desired architectural juxtaposition between the two areas. The living areas to the right and left of the mausoleum were equipped with open fireplaces (Fig.1). Soane appointed “Matthew Boulton & James Watt”, a company which he held in great esteem, to undertake both the concept and the construction of the steam heating system. In addition to their well-known steam engines “Matthew Boulton & James Watt” also started at an early stage to produce steam heating systems (e.g. in 1799 for the Salford Twist Mill). In order to heat the gallery halls, they installed a horizontal, cylindrical boiler (wagon boiler) at the end of the building, which fed the cast-iron pipes with steam.

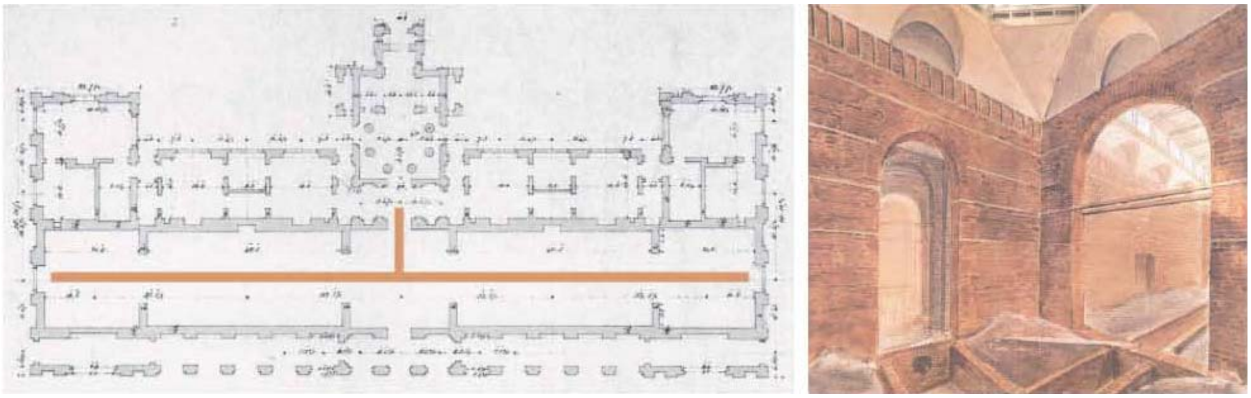

Figure 1: Dulwich Picture Gallery, left – ground floor plan indicating the floor ducts for the steam heating pipes, right – view from the southeast corner of the central gallery room looking northwards to the brickwork flooring ducts following completion of the shell construction, 1812 (

The air heating system, using the example of the Alte Pinakothek in Munich

The two-storey painting gallery in Munich designed by Klenze 1824-36 was also equipped with a central heating system. Both of the gallery floors of the elongated H-shaped building volume were originally to be heated using hot air. In order to produce the heat, cast-iron/masonry ovens were installed in 14 basement heating chambers. These ovens are known in German as "Umsturzfeueröfen" – roughly translated as re-bounding fire ovens. As the fire hit the oven lid, it filled up a narrow circumferential interim space via a rebounding masonry wall (Fig 2, C), thus heating both of the lower parts of the oven. The smoke collected in a horizontal duct and was guided to the chimney from there. The requisite cold air was guided via a duct underneath the oven into the heating chamber (Fig.2). The heated air rose from the uppermost point of the heating chambers via quadratic warm air ducts within the masonry in the ground and first floors and flowed into the gallery rooms through grilled vent openings. Following the principle of air recirculation, the cooled indoor air flowed via a second wall vent and affiliated extract ducts back to the base of the heating chamber to be reheated (Fig 3).

The amounts of both the cold and warm air could be regulated using valves in the heating chamber. In contrast to Dulwich, the heating concept was not developed by an experienced company, rather the court building inspector S. Mayr, responsible for the site supervision, took on this task. Mayr was very well acquainted with the construction of the "Umsturzfeueröfen",

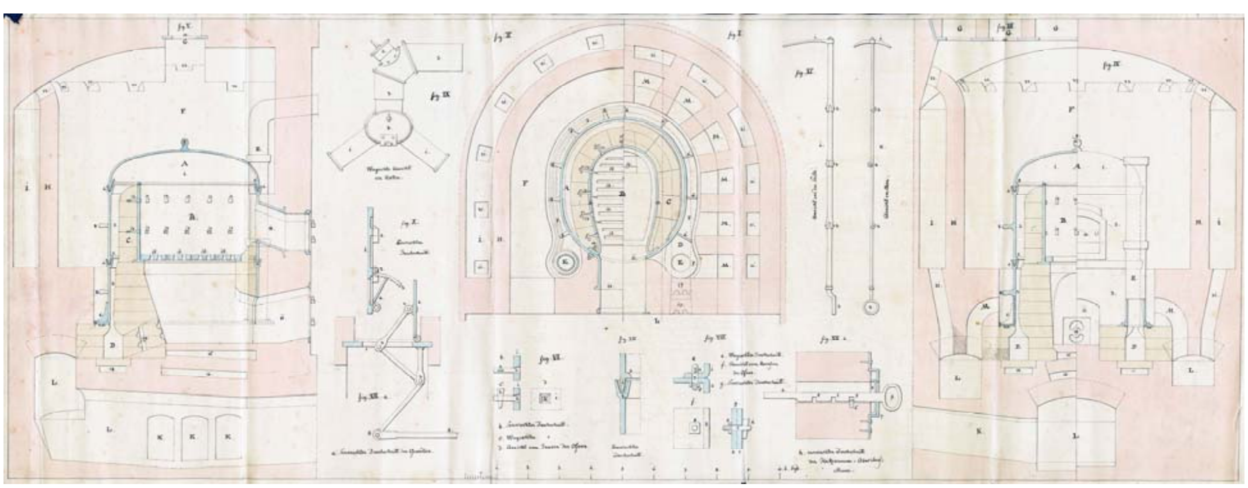

Figure 2: Alte Pinakothek Munich, Plan, section and detail drawings of the constructed cast-iron/masonry ovens and the corresponding heating chambers, 1836 (Archiv Deutsches Museum München)

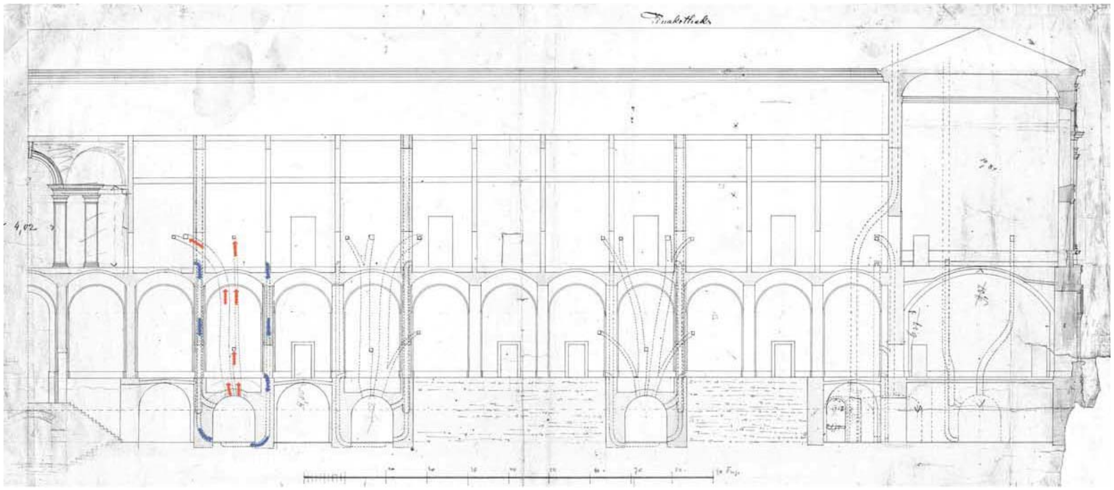

Figure 3: Alte Pinakothek Munich, Section drawing illustrating the warm air ducts (red arrows) and exhaust air ducts (blue arrows) of the air heating system, 1825 (Architekturmuseum der TU München)

implemented on several occasions by the Finnish architect C. L. Engel and published in 1830. Under Mayr's supervision the royal Munich Residence and the Court Church of All Saints in Munich were equipped with an almost identical air heating system.

The air and hot water heating system using Neues Museum in Berlin as an example

The first ever three-storey museum building, the Neues Museum in Berlin, designed by Stüler (1841–1855), was heated using three different types of heating. The longitudinal, almost rectangular construction with two courtyards was equipped not only with an air heating system to heat all of the gallery rooms on the first floor, but also a hot water heating system for the exhibition areas on the 2nd and 3rd floors. The recreation and staff rooms were equipped with individual, locally located ovens.

Two different systems were used for the air heating. The lost heat from the hot water chambers and the heat of the flue gases contained inside the chambers were used for the central wing. The latter was conducted for instance in the northern half of the building via oval "sheet steel flue pipes" in virtually open wall slots throughout all three floors (Fig.4, right). In order to heat the remaining ground floor galleries, six air chambers with cast iron flue pipe ovens were

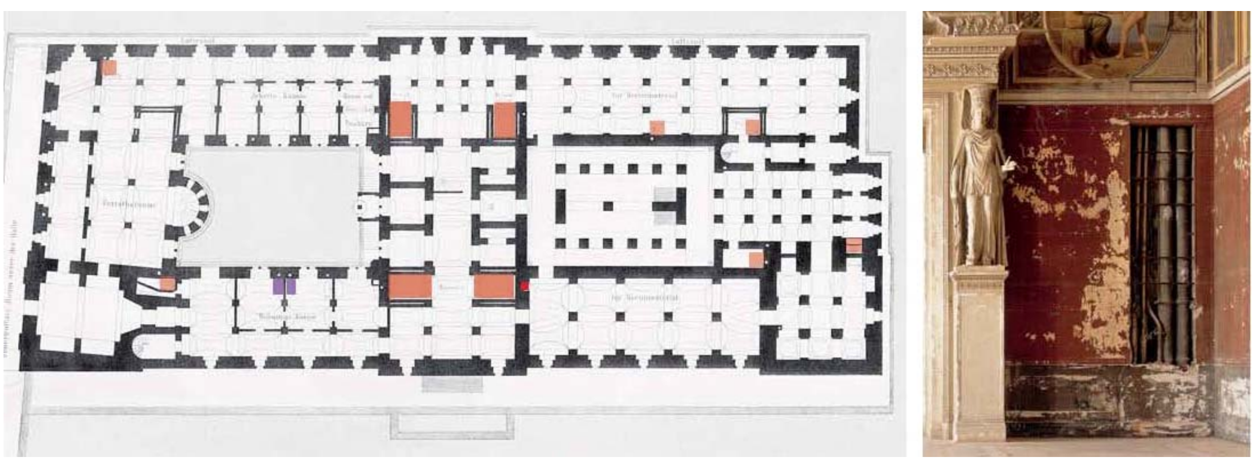

Figure 4: Neues Museum, left – basement floor plan indicating the location of the boilers for the hot water heating (red), the air heating ovens (light red) and the local ovens (violet), 1853 (Architekturmuseum TU Berlin); right – oval smoke flues for the hot water heating in the north wall of Niobid Room, 2003 (J.v. Bruchhausen, Berlin)

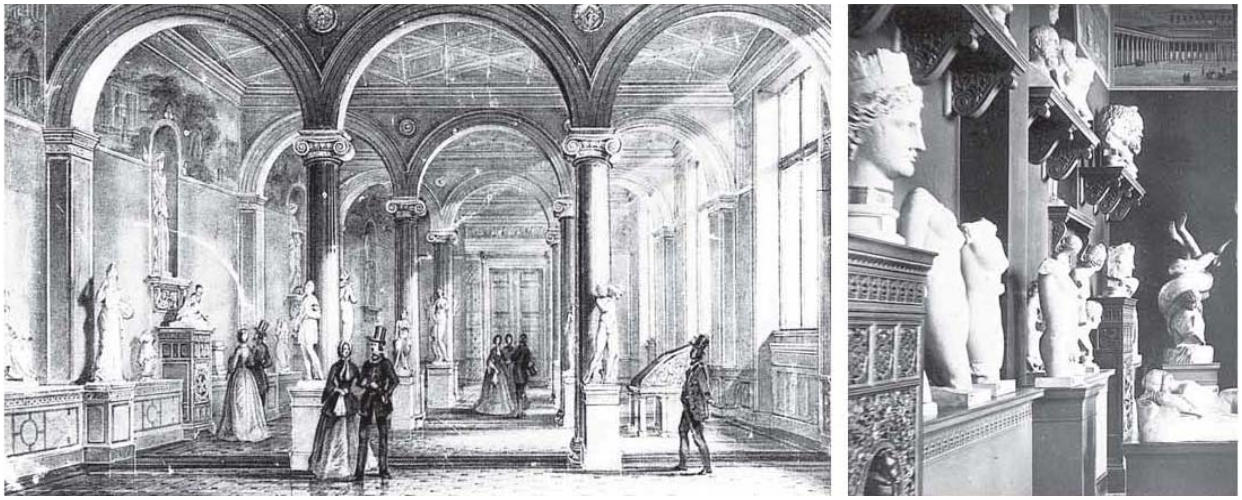

Figure 5: Neues Museum, Roman Room, View of the bricked panels and the hot water oven mantles, concealing the flues of the water heating, Fig. left: approx. 1860; Fig. right approx. 1920 (Bundesamt für Bauwesen und Raumordnung Berlin)

installed in the southern and northern vaults (Fig.4, left). These were known as “flue pipe ovens”, as they had a system of pipes, which snaked up and down in order to increase the heat-dissipating surface. The flue gases created in a bell-shaped combustion chamber released their heat via serpentine-like cast iron socket pipes into the surrounding air chamber, before flowing into the chimney pipe. The heated air then flowed via floor and wall grates into the gallery rooms. The requisite fresh air flowed via adjustable zinc pipes into the air chambers.

Four heating chambers were installed in the vaults of the central wing, underneath the monumental stair hall, for the hot water heating. These were equipped with so-called Cornish boilers, cylindrical forged boilers with interior firing and a simple flue pipe (Fig. 4, left). The water inside, heated to a maximum of 60°C, circulated through copper pipes with joint flanges or through pipe registers, which were directed behind brickwork paneling and within clay jacket furnaces, underneath sandstone slabs in a table form, in circumferential wooden benches with cast zinc grates as well as underneath the flooring in appropriate floor ducts (Fig. 5). In order to compensate the water expansion, two boilers each shared an expansion tank in the attic storey. The relevant installations for filling and emptying the four heating systems were provided in the vaults.

The conception and dimensions of both central heating systems can be found in records drawn up by the architect, Stüler. However the actual selection and dimensions of the implemented systems in accordance with the contemporary technical standards, was the responsibility of the site supervisory engineer Hoffmann, in close cooperation with the manufacturers of the boilers.

THEORY AND PRACTICE – THE DIMENSIONS

For the museums a temperature of 12° to 14°C in the galleries was aimed for. The formation of condensation on the surfaces of the paintings was to be avoided and the centralization of the heating systems far away from the galleries aimed to reduce rust and dust deposits as well as the danger of fire. But how could this be achieved? Were there in addition to the empirical principles already theoretical considerations concerning the determination of heat requirements and the dimensioning of the heat-dissipating surface?

It is self-evident that it was British engineers, who attempted at the beginning of the 19th century to deduce general rules based on practical knowledge. However, the theoretical basis for the calculation of heat requirements was developed already in the first quarter of the 19th century, not in Great Britain, but in France. Both the scientist J.-B. J. Fourier, who analyzed the process of heat conduction in 1807 and began to present this in a partially differential equation, and the physicist J. C. E Peclét must be mentioned here. Peclét summarized in 1828 the theoretical principles of heat and their application in his work entitled “Traite de la chaleur, et de ses applications aux arts et aux manufactures”, which found recognition throughout Europe. But let us return to the practice-oriented considerations.

The British civil engineer, R. Buchanan, noted in 1910 with regard to the proportionate size of steam heating that “It has been ascertained, that one cubic foot of boiler will heat about two thousand cubic feet of space” and “one superficial foot of exterior surface of steam-pipe, will warm two hundred cubic feet of space” if the desired interior temperature is 70 - 80° F [Buchanan, 1815, 161]. Only 14 years later, T. Tredgold indicated, just like Peclét, that it is not just a matter of overcoming the difference in temperature between inside and outside, but that above all the heat dissipation via the building skin and the loss of heat through ventilation must be taken into account. In order to assess the above, he introduced constants and developed a formula for the determination of the required dimensions of heat-dissipating surfaces. A third Brit, the pyrotechnician, C. Hood, modified this in 1841 and compiled simplified tables for the dimensioning of individual elements of hot water heating systems. The German entrepreneur, Wagenmann, also based his calculation approaches for the dimensioning of air heating elements (oven surface, heating chamber, cross-section of duct) in 1827 on Tredgold’s assumptions.

A link between the theoretic and practical knowledge was published by the German physicist, Dr. G. W. Muncke in 1829, providing amongst other things a first compilation of thermal transmission coefficients.

These fundamental principles were used as follows in the three museums presented in this paper: The heating system in Dulwich Picture Gallery was installed by none other than the company Bolton & Watt. A company, which in addition to steam engines had also been manufacturing steam heating systems for greenhouses, factories and residential buildings since the 1780s and who therefore already had extensive practical experience by 1812. This experience formed the basis amongst other things for Buchanan’s and Tredgold’s reflections.

The dimensioning of the air heating system in the Alte Pinakothek in Munich is likewise based on similar empirical values. It was assumed that “the size of the heating chamber equates to one thousandth of the space to be heated” and that “a square foot of heating surface is to be calculated for five hundred cubic meters of room” Hermann, 1835, 155]. The effectiveness of this system was tested beforehand with the first oven, before the remaining 13 cast-iron/masonry ovens were installed. In contrast to this, the air and hot water heating elements in the Neues Museum in Berlin were dimensioned in detail using C. Hood’s calculation approaches.

REVIEW – THE EFFECTIVENESS

The maintenance and repair documents in the subsequent years following completion and the comparison with a reference heating system, where the effectiveness has been substantiated by recorded measurements, are instrumental in estimating the effectiveness of each of the heating systems. The reference heating system with proven effectiveness is represented here by the central air heating system of a Prussian military school, installed in 1827, where we have evidence that in its first years it successfully heated the sleeping and teaching rooms to 12-14° C. The following comparisons are to a great extent based on the relationship between the volume of the room and the heat-dissipating surfaces, firstly as the construction of the building (type of building envelope surfaces, proportion of single-glazed windows…) corresponds well with the construction of the presented museums and secondly the temperature of the heat-dissipating flues gases can be related to the other heat transfer media.

The steam heating system of Dulwich Picture Gallery became the focus of an appraisal analysis at the early stage of 1813 and a second time in 1819, as leakages in the steam pipes provided an optimum breeding ground for dry rot. In other words, this system suffered from the “teething troubles” of steam heating systems, but the assessor J. Rennie also noted “that the gallery may be kept in a proper state of warmth by means of this apparatus” [Willmert,1993, 54]. A highly credible statement, as the comparison with the reference heating system shows, that one to two steam pipes with a diameter of 3 to 4 inches along the hall provide the required heat-dissipating surface.

The air heating system of the Alte Pinakothek in Munich was less successful. Burnt through oven parts had to be replaced already in the first years, the temperature control of the upper floor rooms had to be shut down completely due to the damaging effect of heat accumulation on the paintings in the upper wall area and in the ground floor areas the visitors and museum staff froze as the heated air outlets were situated too high (2 metres above the floor). The comparison with the reference heating system illustrates that the heat-dissipating surface of the ovens should have been double the size, in order to achieve the desired room temperature in both floors. The burnt through oven parts were most probably the consequence of a permanent maximum firing.

The building documents for the Neues Museum dated 1915 include the following comment: the air heating system “consists of an outdated, primitive construction, which does not fulfil the requirements of the modern era” and that the hot water heating causes substantial repair and operating costs. This however means that the original heating systems had been operating for almost 70 years at the time. The comparison with the reference heating system clearly indicates a successful effectiveness of both systems.

CONCLUSIONS

The construction design and functioning of the central steam and hot water heating systems in the first half of the 19th century was dictated to a great extent by the development of the main driving force of the industrial revolution, the steam engine. The heating system in Dulwich Picture Gallery with its boiler from the company Boulton & Watt and the heating system in the Neues Museum in Berlin with its boiler, originally developed by the British inventor and mining engineer R. Trevithick, represent the successful reception of the steam engine boiler. They furthermore illustrate Great Britain’s manifest lead not only in the invention of technical innovations, but also in their widespread implementation. The heating system in the Alte Pinakothek in Munich is on the other hand representative of the stance of the continental Europe. These nations favored, particularly in the first decades of the 19th century, the much less innovative air heating system due to its simple construction, which was hardly susceptible to failure.

The three examples clearly indicate that not only a wealth of experience, but also theoretical knowledge were necessary in achieving a successful dimensioning of a central heating system. In particular the scientific knowledge of thermodynamics was put into practice much earlier than previously assumed. Not only did a new field of planning arise, adopted by the site supervisory engineers, but also a completely new independent branch of industry.

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