QUALITY OF INPUT DATA AT DESIGN OF DISTRIBUTED COGENERATION SYSTEMS

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ABSTRACT:

The quality of input data is essential at designing systems for combined heat and power production. Because of relatively high investment costs, it is needed to select a suitable electrical and/or thermal output, so that the system's yearly utilization ratio is as high as possible. The design should also take into account the maximum and minimum heat and power demand of an object to be supplied. In real conditions, it is very often quite uneasy to obtain precise data of heat and power consumption (like daily load profile) of consumers, usually only monthly or yearly consumption of heat and power is known. This paper tries to assess the impact of data quality on the accuracy of resulting design of a cogeneration system. It shows how even low-quality data can be processed and rearranged in order to gain pretty reliable results.

1. INTRODUCTION

If we want to cover the heat and power demand of a certain consumer by utilization of cogeneration (or CHP) system, we should know the load profile of the consumer during a year. Unfortunately, in most cases such a precise consumption profile is not available, which could hamper the whole process of designing a suitable CHP system in terms of power and heat output [3]. Only monthly or yearly consumption (they can usually be provided by a consumer) are not enough for a proper design as I'll show next, anyway, they can be processed in such a way to make them usable.

2. SIMPLE APPROXIMATION OF MONTHLY CONSUMPTION

An algorithm for solving such a task (design of CHP system based on monthly consumption) is described in details in [1]. The algorithm is used in a computer application that performs the calculation. The idea is as follows. For each of two types of energy demand, thus heat and power, monthly consumptions are known, it means twelve values for each. Because the calculation in the program is being carried out in hours (for each hour of a year, i.e. in range from 0 to 8760), we need to transform the monthly consumption into hourly consumptions (hourly consumption in kWh is in fact an average demand in kW during one hour). In order to do that, monthly consumptions are approximated by a polynomial of 4[th] degree through the method of least squares. The resulting polynomial has the following form (1).

$$Cons(x) = c_4 \cdot x^4 + c_3 \cdot x^3 + c_2 \cdot x^2 + c_1 \cdot x + c_0, \qquad (1)$$

where c_i are coefficients of the polynomial and x corresponds to months, transformed into hours. The graphic representation of the approximation is depicted in **Fig.1**.

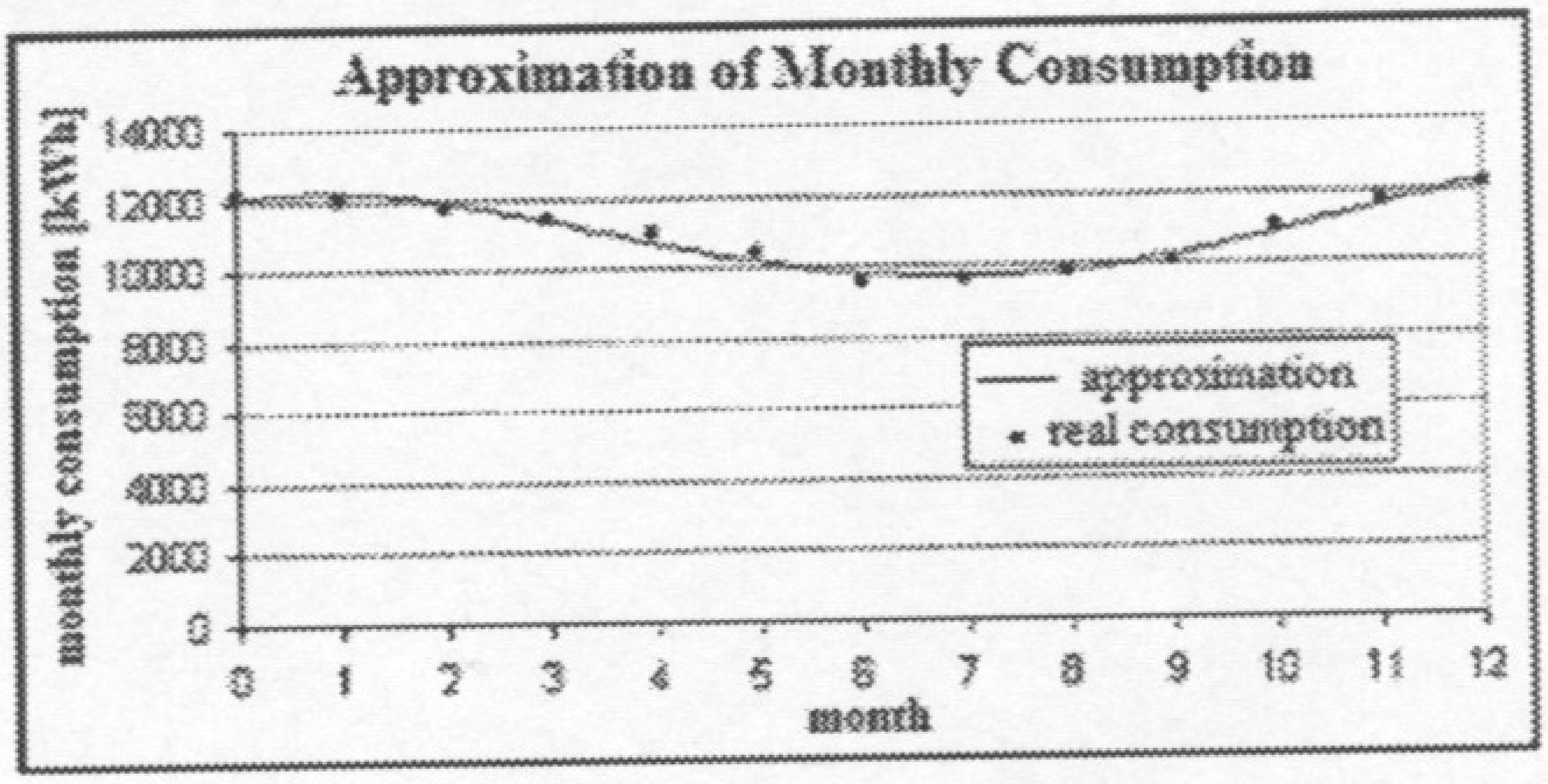

Fig. 1: Approximation by a polynomial using the method of least squares

These values of hourly consumptions are then used in iterative calculations for the whole year.

This approach using just approximation by polynomial seems sufficient only for a certain range of tasks. It is usable with high enough accuracy only when the consumption is relatively stable and changing quite slowly during a day and week, as an example we can take a swimming pool (this task was solved in [1]). However, using this method, any daily peaks and daily lows that are very common in most cases do not show up. It makes this method in those cases too inaccurate, as shown in the next paragraph.

3. DRAWBACKS OF SIMPLE APPROXIMATION

In order to assess how much the described approximation method simplifies the real course of consumption (real load profile, which is generally unknown), I used the following procedure:

a) In the **first step**, I invented a yearly load profile, which takes into account the changes in heat and power demand during a day. For each month of the year, I know a daily load profile (heat and power) during a typical working day and on weekend day. I put all the data together in an appropriate way, so that I receive yearly load profile (heat and power demand for each hour from 0 to 8760). Thus, in this case, no approximation curve is needed. The resulting load profile is graphically depicted in **Fig.2**; corresponding load duration line is in **Fig.3**.

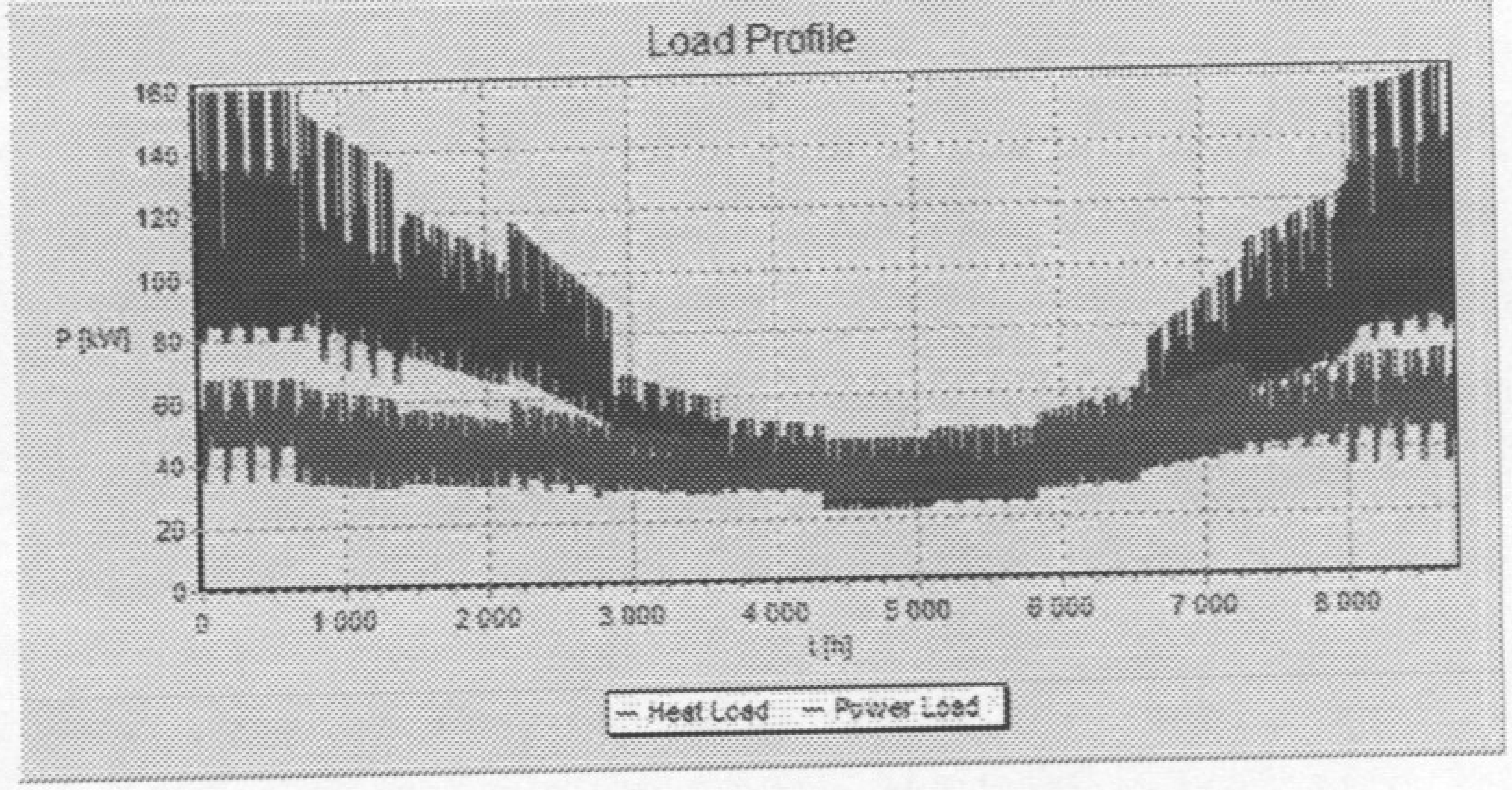

Fig. 2: Yearly load profile based on the typical daily load profiles for each month

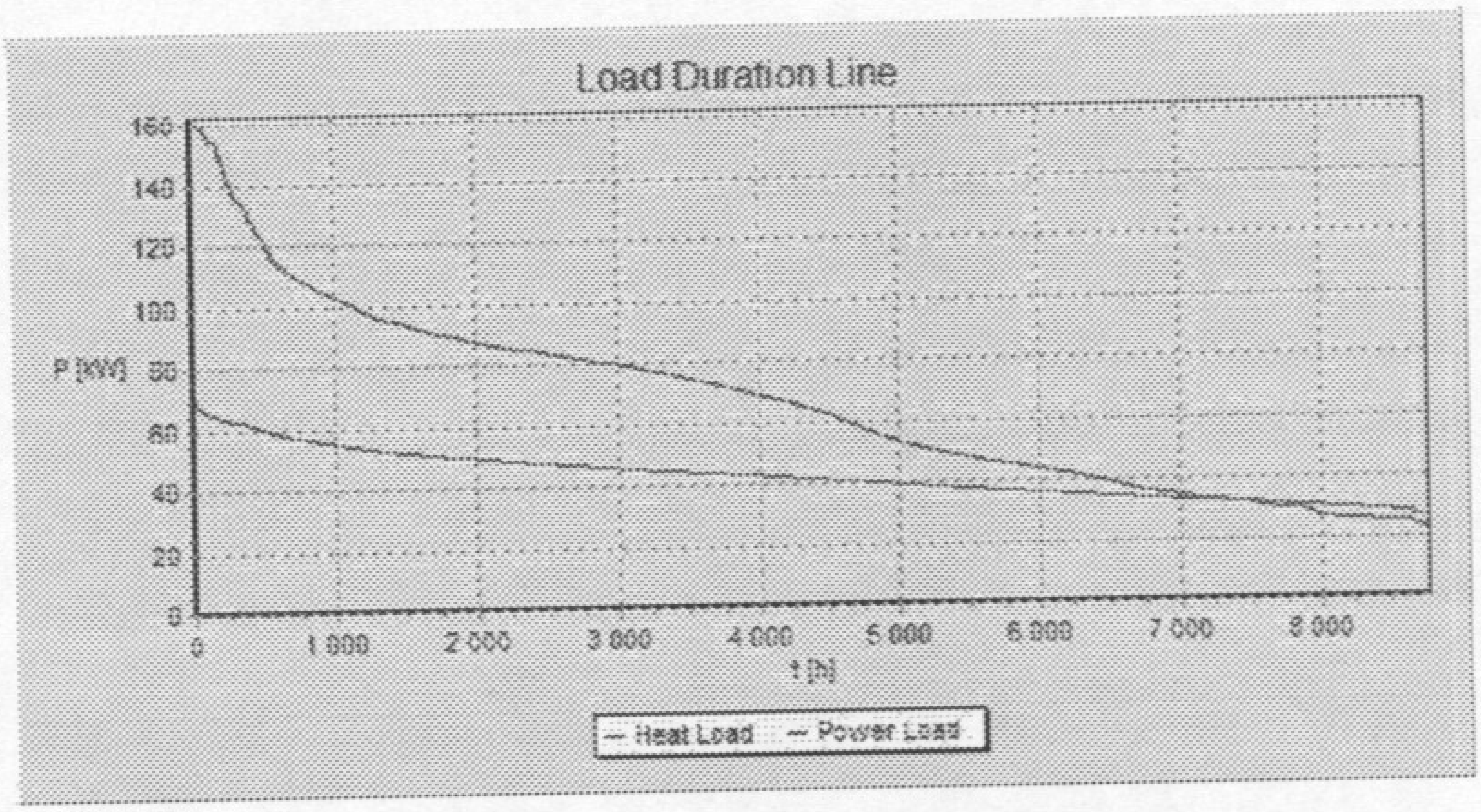

Fig. 3: Load duration line corresponding to load profile from Fig. 2

b) In the **second step**, I sum up the hourly consumptions of heat and power for each month (for January 31 days, February 28 days, etc.) in order to receive monthly consumptions. The total yearly consumption remains the same. The obtained monthly consumptions are further processed in the same way as described in paragraph 2 (thus approximation by a polynomial of 4th degree). The new resulting approximation curve is displayed in the same graph as the original yearly load profile; see **Fig.4** and **Fig.5** corresponding to heat demand. The representation of power demand is very similar, except of the differences are not so outstanding. It is obvious in both of the two figures that the approximation is in fact a kind of mean value that doesn't take into account the fluctuation in demand during a day. The approximation polynomial is very different from real curve. It represents the change between individual months (e.g. different demand in winter month and summer month) but neglects daily changes. It can result in a significant mistake, as shown in this particular example.

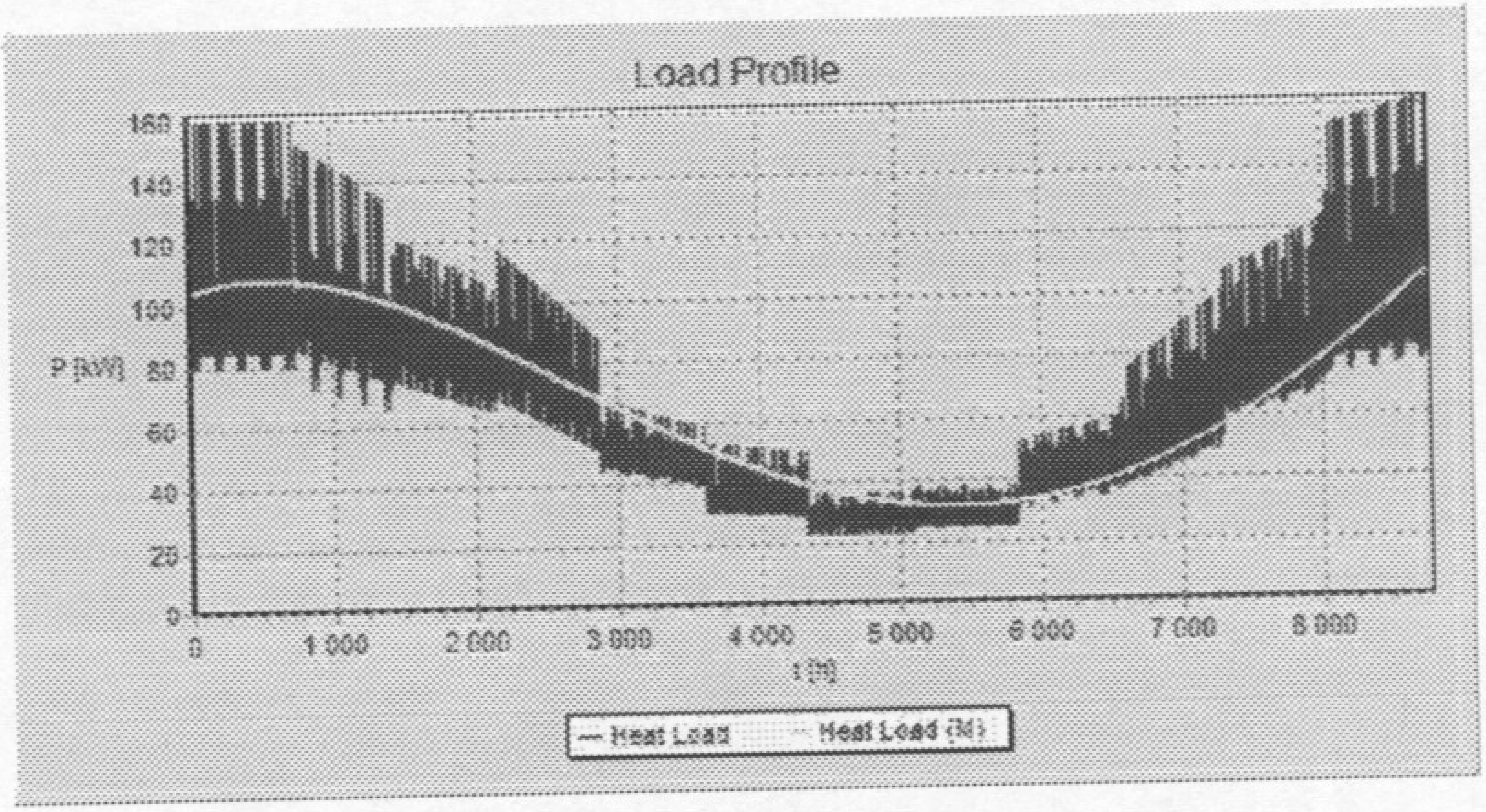

Fig. 4: Comparison of load profiles (hourly heat consumptions, approxim. monthly heat consumptions)

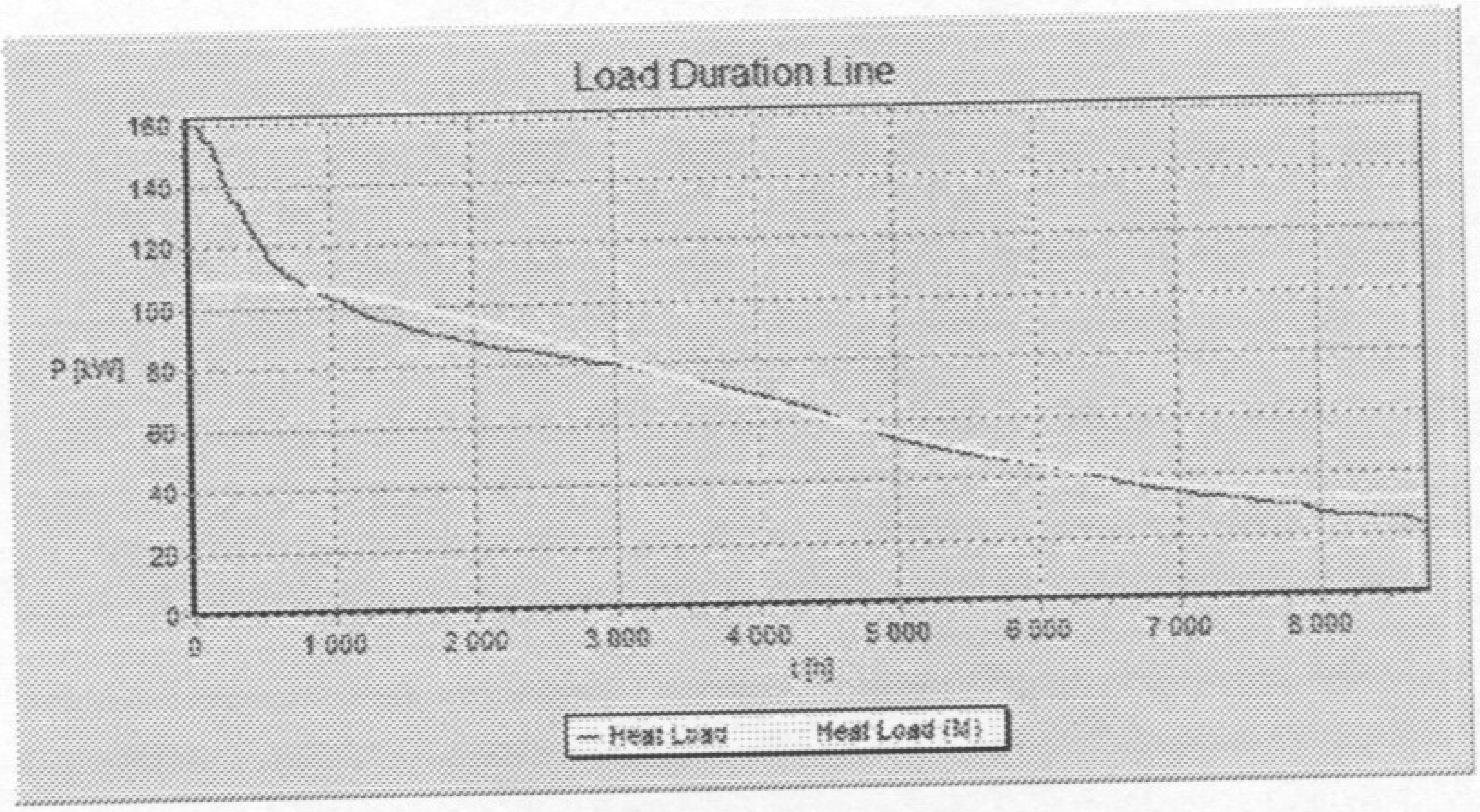

Fig. 5: Load duration lines of heat demand corresponding to load profiles from Fig. 4

The maximum demand is a very important value. We have to select such a system that can cover this maximum demand. According to approximation curve in **Fig.4** and **5**, the maximum heat demand during a year is about 110 kW. But according to real curve based on hourly consumptions, the maximum heat demand is about 160 kW, which is much more than 110 kW. If we selected the rated CHP system's output based on approximated curve, e.g. 120 kW, the system wouldn't be able to supply demanded heat in the peaks up to 160 kW. The similar situation comes with the power demand: the maximums of real and approximation curves are too different.

The reason is clear, as I mentioned before. This method of approximation cuts the peaks and fills the lows, in other words erases daily fluctuation in heat and power demand. This is something that we cannot accept at designing the rated output of the system. This approximation is thus usable only in those special cases of stable demand, when the daily fluctuations are marginal, which are only seldom found under real conditions. In most cases an improved approximation method is needed.

4. SIMPLE APPROXIMATION WITH SINE FUNCTION

Daily fluctuation in demand can be quite easily simulated by the sine function. This function is very advantageous for this purpose – it is periodical and the mean value of the function in one whole period equals 0. It is a necessary condition. By adding a modulating function to basic approximation curve, we cannot afford to change the total yearly consumption, which must remain the same. If we modulate the sine function on the approximation polynomial, this condition is met. Next it must be found, what period in hours and what relative daily fluctuation is suitable (we have to set parameters of the sine function).

Every type of consumer (e.g. household, bank, school, hospital, hotel, factory, etc.) is characterized by a certain (typical) load profile. The shape of the load curve is for each group of consumers typical and can be based on historical measurements. It is a very important fact – if we know the type of a consumer, we can quite precisely assume his yearly load profile, even if we do not know his hourly load profile. Then it should be enough to know only monthly or even yearly consumption of heat and power. This, together with the knowledge of the type of a consumer, may be sufficient for the construction of a relevant yearly load profile.

Following pictures, see **Fig.6** and 7, are based on the real data from Austrian power utility KELAG (see [2]), which supplied typical load profiles for groups of consumers. As an example, I took the data of power consumption for a "household" in summer period and for an "administration building" in winter period.

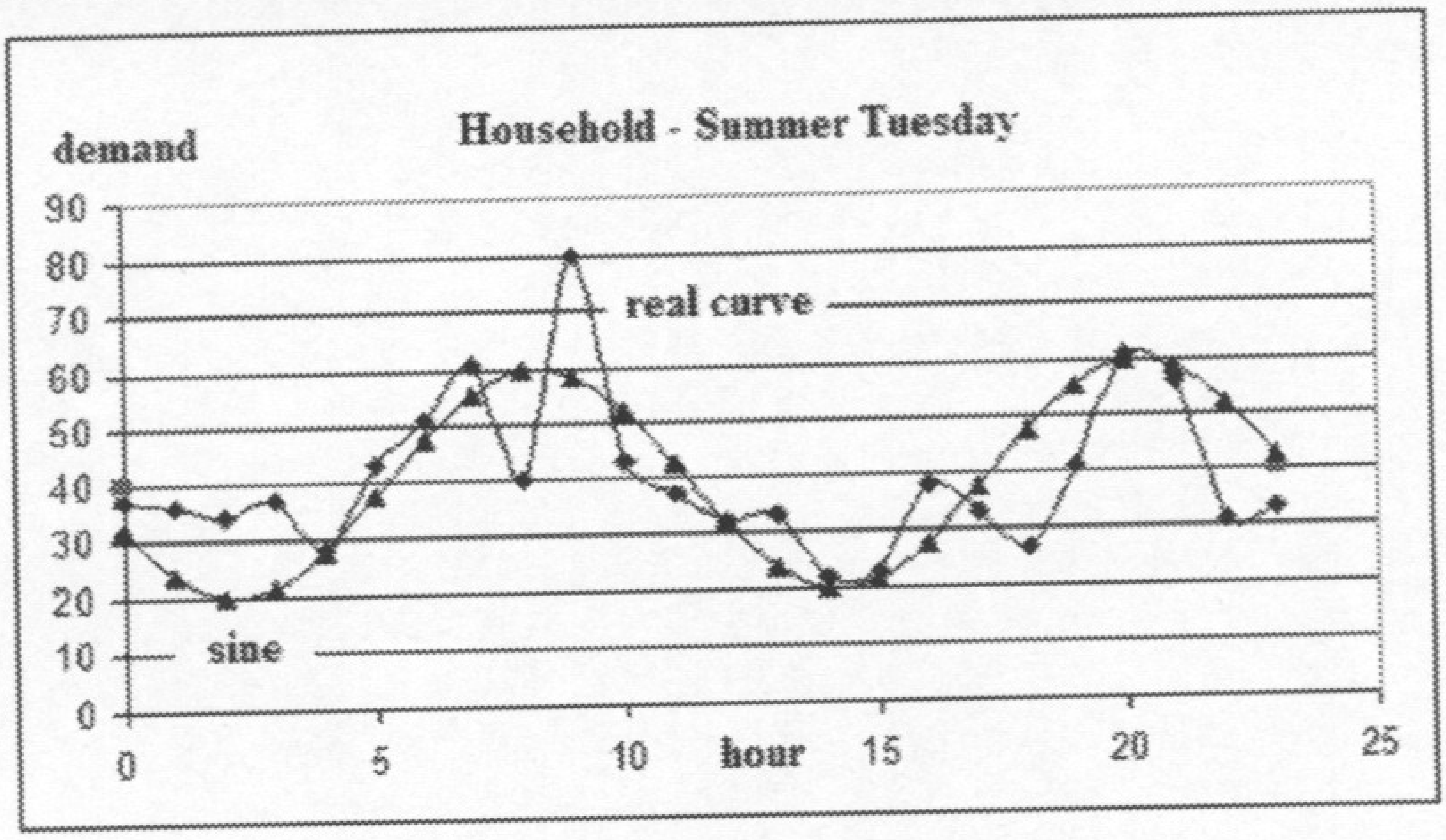

Fig. 6: Typical daily load profile for „household", based on the data from KELAG utility

The introduction of modulating sine function results in this equation (2).

$$NewVaulue(x) = Value(x) + A \cdot \sin\left(\frac{2\pi}{T} - shift\right), \qquad (2)$$

where *x* means hour in year, *Value(x)* is the original value (in fact mean value), *A* stands for amplitude of the sine function, *T* for its period and *shift* corresponds to the phase (offset) of the sine function.

In both mentioned examples (i.e. household and administration building), the relative amplitude is 0.5 (i.e. daily fluctuation is +/-50 %). The period T is 12 hours for household, while 24 hours for administration building. For other groups of consumers similar or slightly different parameters can be found.

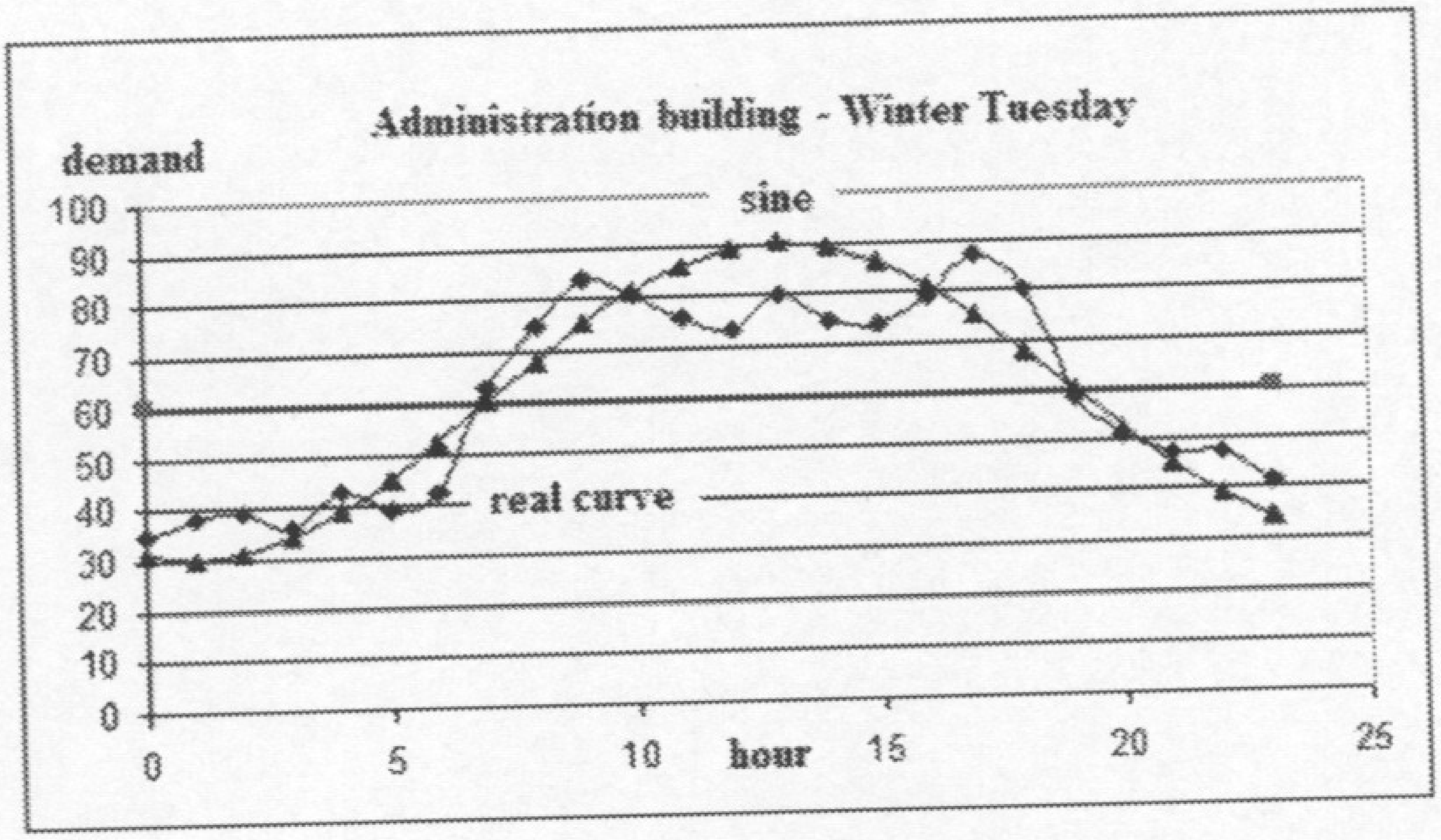

Fig. 7: Typical daily load profile for „administration building", based on the data from KELAG utility

With this approach (i.e. modulation of an appropriate sine function on the approximation polynomial) the whole approximation method can be significantly improved. We can then obtain a relevant yearly load profile based on the monthly consumption only, provided that we have the knowledge of the consumer's type (and thus characteristic daily load profile). The procedure has two parts as follows:

i) Approximation of monthly consumptions through the method of least squares, resulting in an approximation polynomial (see paragraph 2 of this paper or [1])

ii) Modulation of an appropriate sine function on the approximation polynomial

The improved results are depicted in **Fig.8** and **9**, corresponding to yearly power load profile. It is obvious that this time the curves are much more similar, the differences in maximum power demand is marginal (in both cases about 70 kW).

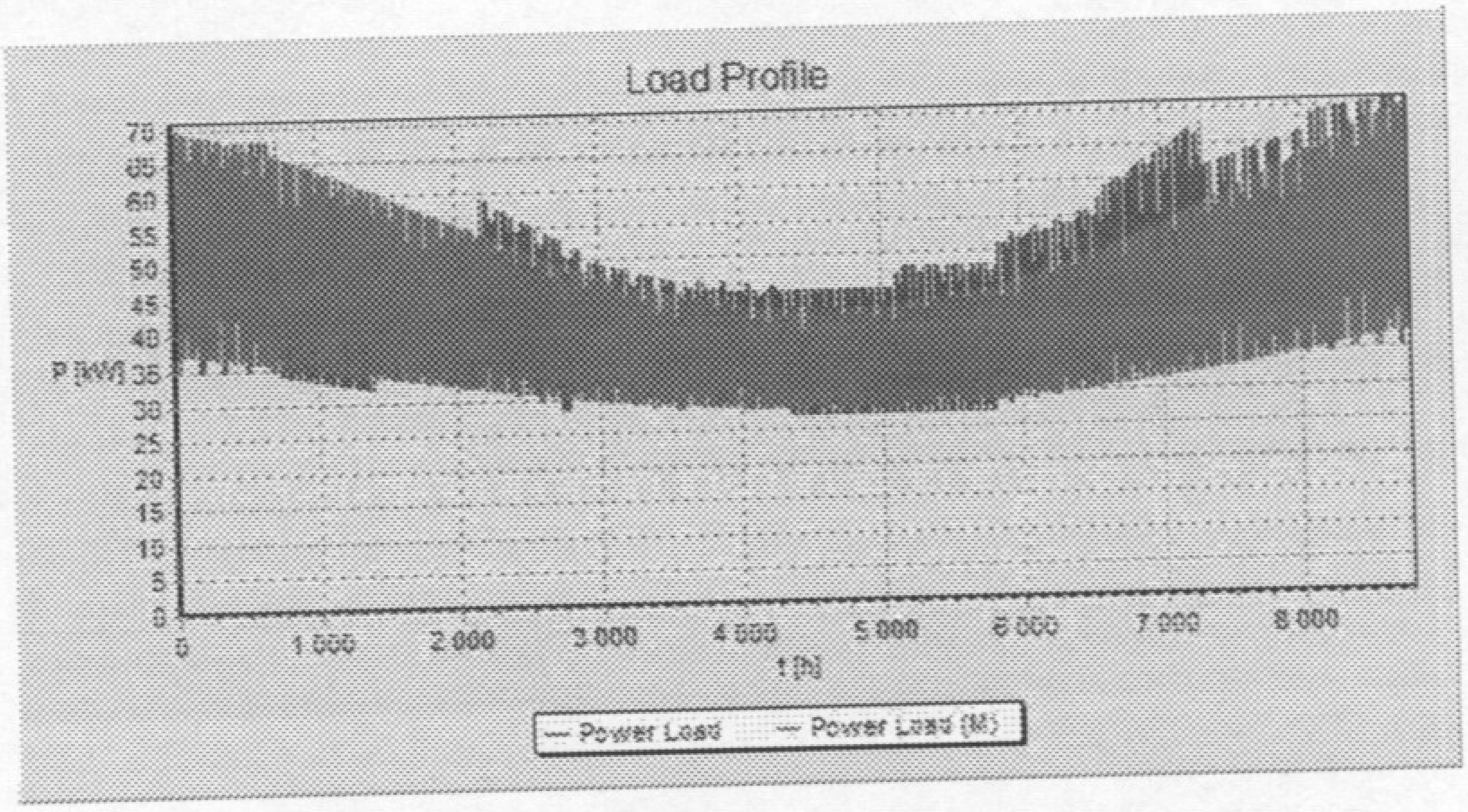

Fig. 8: Comparison of yearly power load profiles (hourly values, monthly approximation with sine modulation)

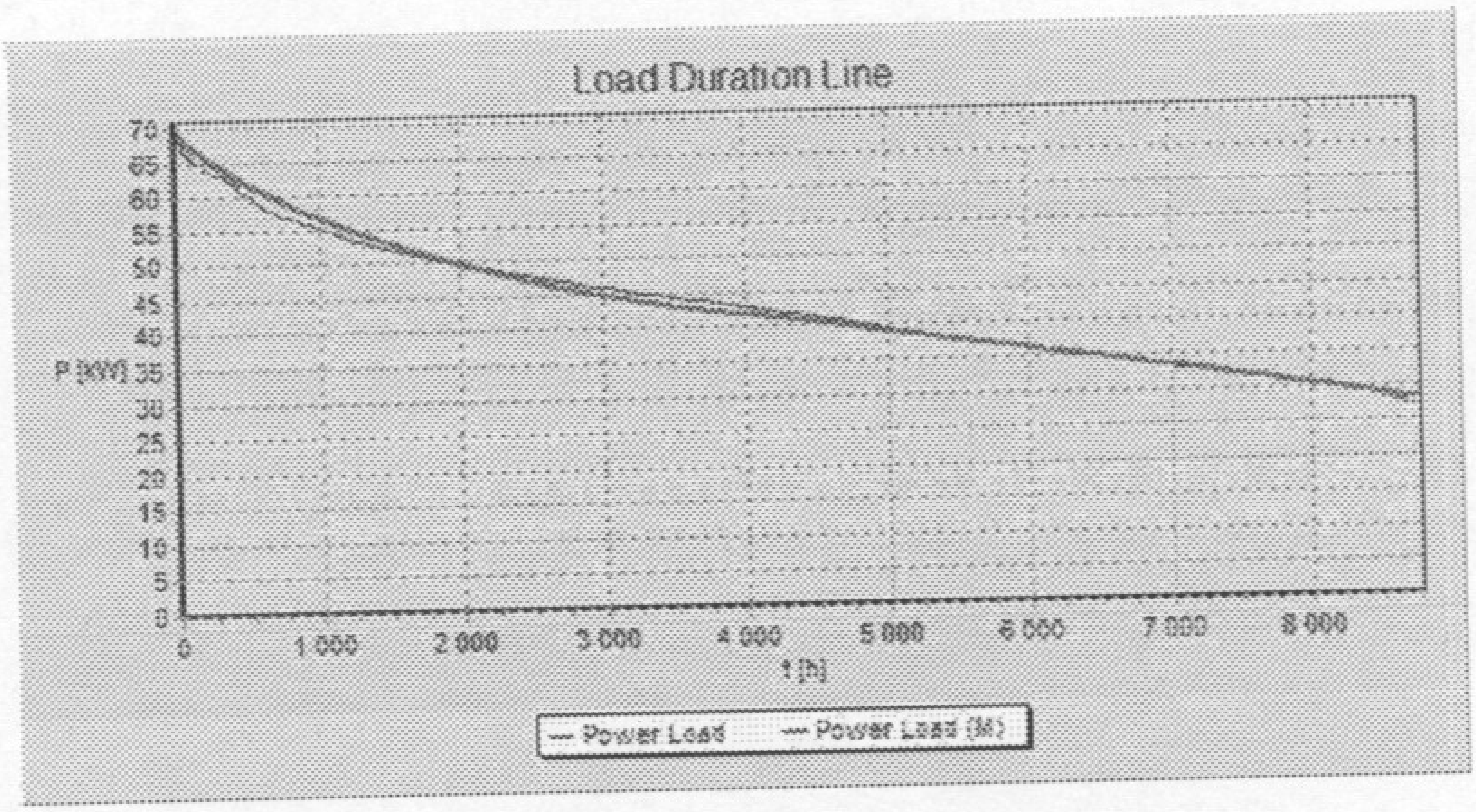

Fig. 9: Load duration lines of power demand corresponding to load profiles from Fig. 8

5. CONCLUSION

The described improvement of the approximation method used in [1], which is based only on monthly consumptions is principally quite simple. It consists in modulating of a sine function with suitable parameters on the basic approximation polynomial obtained from monthly consumptions in the same way as in [1]. This approach takes into account daily fluctuation in heat and power demand and thus leads to much more solid results, as shown graphically in previous paragraphs. The method can be further improved, e.g. by adding module that respects weekly fluctuation (differences in consumption on weekdays and on weekends), which is not regarded in this paper. Using this improved method at designing CHP systems, good solutions can be found even in such cases, when only limited amount of input data is available (e.g. monthly consumptions, yearly consumption).

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