

Analysing Office Building Water Network Data Using Computational Methods

Mika Raatikainen^{a*}, Jukka-Pekka Skön^a, Markus Johansson^a, Minna M. Keinänen-Toivola^b and
Mikko Kolehmainen^a

^aUniversity of Eastern Finland, FI-70211 Kuopio, Finland

^bPrizztech Ltd./WANDER NordicWater and Materials Institute, FI-26100 Rauma, Finland

Abstract. The continuous measurements of water pressure and temperature and multivariate methods are applied in researching of building water network, especially water hammer phenomenon. Measured data used in this study was collected continuously in an office building located in Rauma, Western Finland, during seven days long period. Parameters measured were values of cold water pressure and temperature, hot water pressure and temperature and temperature of mixed water. In this study, self-organizing map (SOM) was applied to resolve the dependencies of water pressures and temperatures. Because of the property to summarize the multivariable dependencies into easily observable two-dimensional map, the SOM was qualified as a suitable method of finding dependencies between tap water usage and water pressures and temperatures. The results indicate that variation of hot water pressure was significantly larger than in cold water. This holds true also during the tap usage and the periods of tap nonuse. In addition, this paper presents results of an adequate sampling rate to recognize water hammer phenomenon in the building water pipelines.

Keywords: Water network ; Water hammer ; Neural networks; Self-organizing map ; Hydraulic modelling

1. Introduction

Water and its resources is a widely researched topic, because of its diverse effects on people's everyday life. Artificial Neural Networks (ANNs) has been applied to predict and forecast water resources variables [1]. Increased interest and research on water networks and building potable water pipelines are important, because of water quality, leakage reduction and energy efficiency of water distribution systems. There has been developed an algorithm for the detection and location of sudden bursts in water distribution networks combining both continuous monitoring of pressure and hydraulic transient computation [2]. For example, the durability of pipe networks is affected by water hammer phenomenon. That is why it is useful to be aware of both historic developments and present day research and practice in the field of hydraulic transients [3]. The global energy performance, hydraulic power capacity and energetically maximum flows in pipes and networks has been determined in a water distribution system, which consists of distribution network and pumping station [4]. For better water quality there has been created a model for optimizing the placement of sensors in municipal water networks to detect injected contaminants [5]. Drinking water may contain residual biodegradable dissolved organic compounds which provide a primary source for the formation of a trophic chain inside the pipes. There has been proposed a model for the study of the behavior of bacterial biomasses in distribution networks [6]. The model makes use of the data supplied by the hydraulic modeling software, which can provide predictive mapping of the situation of each section of the network. This paper describes methodology used in water temperature and pressure measurements. The collected water pipeline data is an input for self-organizing map (SOM), which is used to express the dependencies of water pressures

* Corresponding author.

E-mail address: mika.raatikainen@uef.fi.

and temperatures. The figures and curves has been analysed to understand the duration and form of water hammer.

2. Materials and Methods

2.1. Study building

Study building Sytytin is a technology and innovation centre located in Rauma, Western Finland. The water distribution system of the building is designed, also, for full-scale research purposes. It obtains its drinking water from the Rauman vesi, the local water supplier. Supplied water is made of surface water and it is chemically purified with a process including sedimentation, flotation, and disinfection [7]. The water distribution system has been planned and installed according to current legislation and protocols in Finland. In addition, system is a research complex consisting of pipe collectors, sampling faucets and water meter with remote and continuous water quality monitoring. These systems enable comparison of different pipe materials and sampling of water. The research distribution system incorporates both cold and hot water pipelines. There are several pipe materials in the pipelines in different parts of the building; plastic cross-linked polyethylene i.e. PEX and metal i.e. copper. In addition, there are two heat exchangers in the building not to mix hot water within PEX and copper pipelines. In the basement, there is also a multilayer pipeline for cold water.

2.2. Data collection and processing

The case study data was collected by using Oras-measurement system (Dataq Instruments, DI-718B Series) connected to water distribution system at room 136. Measurement sensors were connected to cold and warm water pipelines close to tap. Also, there were an additional sensor installed on tap output measuring mixed water temperature when draining and ambient air when not draining. Room 136 is a regular office building toilet, where all users indorsed their tap usage during the study period. In addition, there is another toilet, room 134, beside the room 136. Both taps located in the toilets are connected to same cold and hot water pipelines. The reference toilet 134 was not equipped with any measurements. But, also there was the tap usage indorsement used in the room 134. The collected data consisted of measurements of pressure (cold and hot water), temperature (cold and hot water) and mixed water temperature. Measured variables and their ranges are presented in Table 1. The size of the collected data matrix was 122 million rows, and 6 variables in columns during the period of 7 days. There were no missing data or outliers.

Table 1. Variables, units and ranges

Variable	Unit	Range
Time stamp	ms	November 1-7, 2011
Pressure, Cold water	bar	2.8 - 11.6
Pressure, Hot water	bar	1.7 - 13.3
Temperature, Cold water	°C	15.9 - 26.2
Temperature, Hot water	°C	22.2 - 55.5
Temperature, Mixed water	°C	17.5 - 45.6

The information of the tap usage (time) in rooms 134 and 136 was recorded by users. These recorded times were transformed as an additional variable; 0 means no usage in either toilets, 1 means tap usage in room 134 and 2 means tap usage in room 136. Sampling rate was set to 200 Hz. It means, that we had samples every 5th millisecond on five channels. The measurement frequency was more than adequate to identify rapid changes in water pressure and express the form of water hammer.

2.3. Self-Organizing Map

The Self-Organizing Map (SOM) is a neural network algorithm developed by a Finnish academician Teuvo Kohonen in early 1980ies. The common purpose of SOM-method is to perform data analysis by

mapping n-dimensional input vectors to the neurons, and visualizing results in a two-dimensional lattice [8]. In the two-dimensional lattice, the input vectors with common features effect on the same or neighbouring neurons, preserving the topological order of the original data. The SOM learning process is unsupervised: there is no need for a priori classifications for the input vectors. A large variety of SOM-based applications have been developed during the last three decades. The common application fields of SOM are, for example in machine vision, signal processing, exploratory data analysis and in pattern recognition [9].

2.4. Analysing measured water data

The water measurement data was coded into inputs for the self-organizing map. All the input values were normalized by variance scaling and permuted before training the map with five latest variables presented in Table 1. After training, a SOM having 100 neurons in 10 x 10 hexagonal grid was constructed. Linear initialization and batch training algorithm were used in the map training. The Gaussian function was used as the neighbourhood function. The SOM Toolbox version 2.0 (Aalto University, Laboratory of Computer and Information Science) was used in the data analysis under a Matlab-software platform (Mathworks, Natick, MA, USA).

3. Results

The statistical properties of water pressures and temperatures are presented in Figure 1 (a) and (b). The range of hot water pressure is larger than in cold water, Figure 1 (a). Also, there have been more and bigger water hammers in hot water network. November 6th, 2011 was Sunday and there has been a little of water usage in the office building.

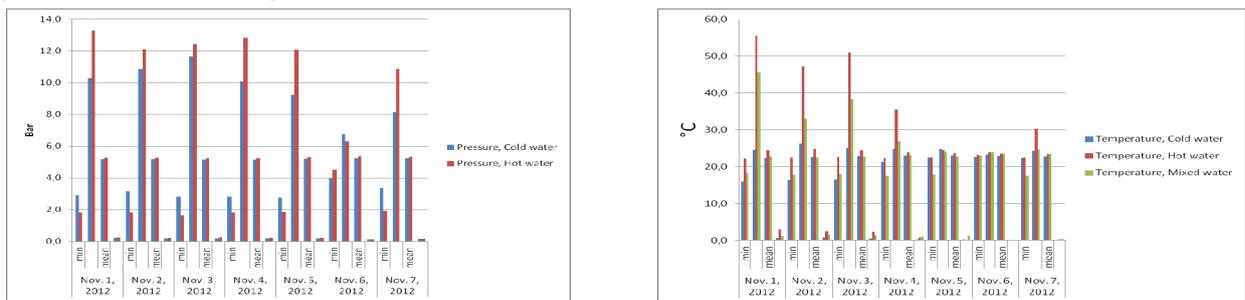
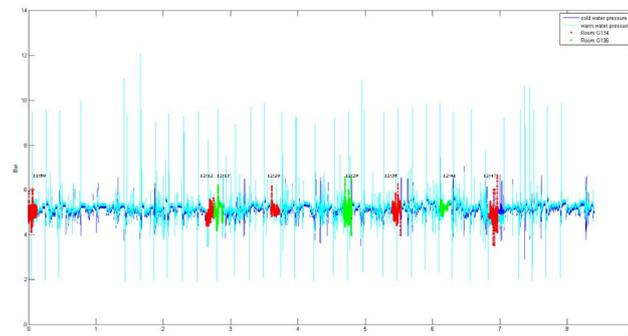


Fig.1. (a) Water pressures in hot water pipelines have larger range than in cold water pipelines. In the x-axis there are drawn minimum, maximum, mean and standard deviation of daily pressures,; (b) Daily water temperature variations are drawn in the figure with their minimum, maximum, mean and standard deviation values.

All three temperatures in the Figure 1 (b) were in the same level on Saturday and Sunday when there was almost no use in the water pipelines.



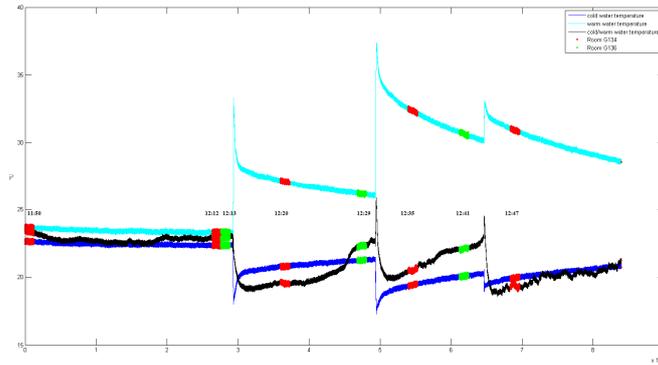


Fig. 2. (a) Water pressures and tap usages during the one week. Green periods are one minute tap usages in the study room 136 marked on Figure 2 (a). Red periods are one minute tap usages in the reference room 134 marked on Figure 2 (a). A blue curve is a cold water pressure and a light blue curve is a hot water pressure. ; (b) Water temperatures and tap usages during the one week. A blue curve is a cold water temperature and a light blue curve is a hot water temperature. A black curve is a mixed water temperature.

Water hammer phenomenon can be noticed in Figure 2 (a), especially in hot water pipeline. There have been lots of water hammers between tap usage. There can be seen variation in temperatures close to time of tap usage. Hot water temperature arises for a while and cold water temperature decreases.

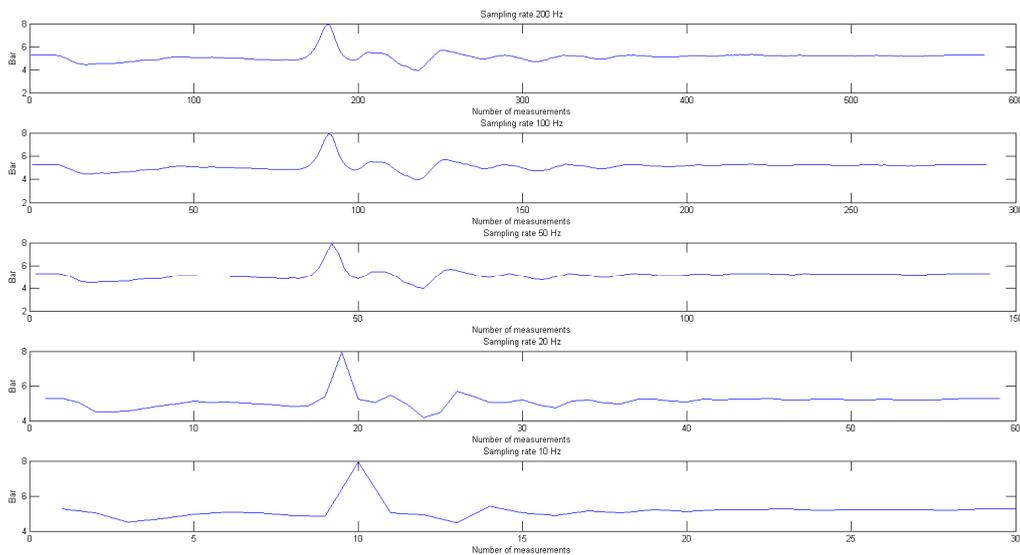


Fig. 3. Comparison of sampling rates. Sampling rate of 50 Hz is adequate to recognize the water hammer phenomenon.

The adequate sampling rate for recognizing the water hammer phenomenon has been researched in Figure 3. Even in sampling rate of 50 Hz the variation and the form of water hammer can be identified. The sampling rate used in measurements was 200 Hz.

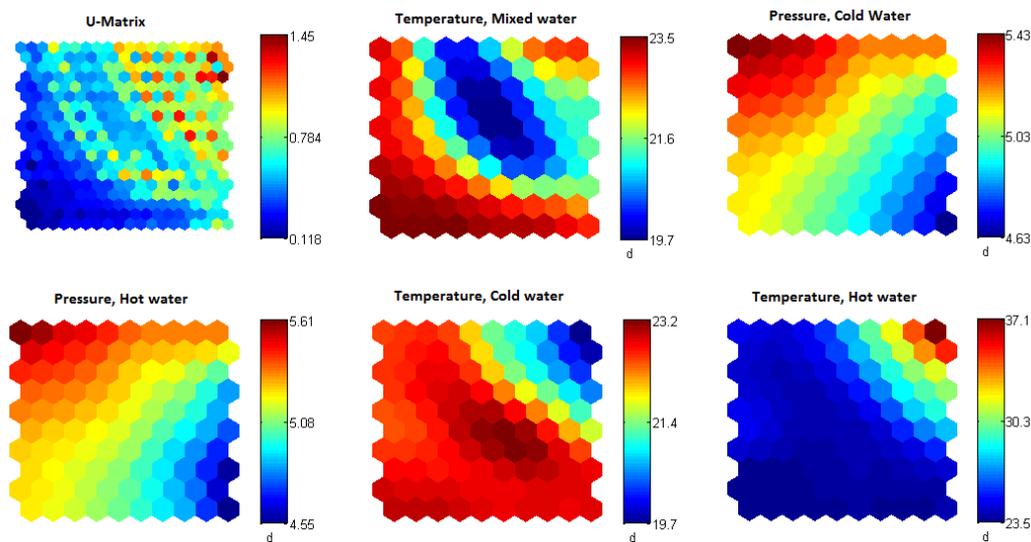


Fig. 4. Component planes of SOM reveal, that there are no dependencies between pressures and temperatures. U-matrix (unified distance matrix) profile the mutual distances of reference vectors and shows the potential clusters.

Comparing the variables on the SOM component planes during the tap usage, the water temperature does not have impact on pressure, which is natural, and could be seen in Figure 4. The neurons in pressure planes and temperature planes are clustered in the different areas, in separate corners. In the neurons with low or high temperature, the pressure is not corresponding.

4. Conclusion

We have achieved preliminary results of researching water pressure and temperature when water flows due to tap usage. Contrary to the methods used in references, SOM can reveal the unexpected connections in multivariate data. Method used, SOM, could expose some features of dependencies, but additional variables concerning water flow are needed. In this study the authors clarified the adequate sampling rate for recognizing the water hammer in the office building pipelines. Concerning the sampling rate of measurements the lower frequency could be recommended to decrease the amount of recorded data. For further results and for studying the water hammer impacts to pipeline materials and durability, more methods like predictive modeling could be applied. In addition, more pressure and also same time water consumption measuring is needed to understand better pipelines behavior. Further, we are going to study flow rate products in pilot building based on pressure measurements and hydraulic modeling.

5. Acknowledgements

This research was done as a part of the Finnish iENV-project (USER-CENTRIC INDOOR ENVIRONMENT). For financial support, the authors would like to thank the Finnish Funding Agency for Technology and Innovation (Tekes), and all the companies that have been involved in the iENV-project task 4: Oras Oy, Uponor Oy and Cupori Group Oy.

6. References

- [1] Maier HR, Dandy GC. Neural networks for the prediction and forecasting of water resources variables: a review of modelling issues and applications. *Environmental Modelling & Software* 2000;Vol. 15:101-124.
- [2] Misiunas D, Lambert MF, Simpson AR, Olsson, G. Burst detection and location in water distribution systems. *Water Science and Technology:Water Supply*, Vol. 5:71–80.
- [3] Gridaoui MS, Zhao M, McInnis DA, Axworthy DH. A Review of Water Hammer Theory and Practice. *Applied Mechanics Reviews* 2005;Vol. 58:49-76.
- [4] Vaabel J, Ainola L, Koppel T. Hydraulic Power Analysis for Determination of Characteristics of a Water Distribution System. *Proceedings of the 8th Annual Water Distribution Systems Analysis Symposium* 2006.
- [5] Berry JW, Fleicher L, Hart WE, Phillips CA, Watson J-P. Sensor Placement in Municipal Water Networks. *Journal of Water Resources Planning and Management* 2005;Vol. 131:237-243.

- [6] Dukan S, Levi Y, Piriou P, Guyon F, Villon P. Dynamic Modelling of Bacterial Growth in Drinking Water Networks. *Wat. Res.* 1996;Vol. 30:1991-2002.
- [7] Prizztech Ltd./WANDER Nordic Water and Material Institute. Web page. Can be found at: www.prizz.fi/wanderwater.
- [8] Kohonen T. Self-organizing maps, 3rd ed. Springer-Verlag: Berlin Heidelberg; 2001.
- [9] Haykin S. Neural Networks-A Comprehensive Foundation. 2nd ed. New Jersey: Prentice-Hall Inc; 1999.