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Studying a Hospital Distribution Network with a Stochastic End-uses Demand Model

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Abstract

The schematization of a hospital water network through a probabilistic model of end-uses is the focus of this study. The idea is to realize a model to evaluate the water demand related to the use of individual water-demanding devices to define a strategy for the prevention and control of legionella risk. The modelling of hospital network has been carried out through EPANET 2.0 software [1], in which the hot and cold water networks can be implemented separately. The suggested probabilistic model has already been applied to several case studies [2, 3, 4, 5], but never to a hospital network.

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1. Introduction

The heavy problem of infections contracted during hospital stays is recognized worldwide as one of the major threats to public health [6]. Nevertheless, nosocomial infections continue to pose a severe public health problem being legionnaires' disease a serious infectious disease highly lethal. Over the past three decades, the topic of infection control has grown in importance because of the suffering and additional costs associated with nosocomial infections as well as to their avoidance measures already known. Up to 30% of pulmonary infections acquired in hospitals is caused by the bacterium Legionella, which gives its name to the disease known as Legionnaires' disease (or legionnaires' disease). A case of nosocomial Legionnaires' disease is defined when the infected patient has been treated in hospital continuously for more than 10 days before the onset of symptoms. Two or more cases occur in the

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hospital within six months are defined as an epidemic hospital. The contamination by the Legionella bacterium occurs because of its migration inside of water pipelines of sanitary hot water in which there are optimal conditions of survival due to the high temperatures, low speed and the presence of biofilm, which represents its nourishment. Infections with Legionella spp. (particularly those caused by Legionella pneumophila) represent an important public health problem, so that they are subjected to special surveillance by the World Health Organization, the European countries and the Institute of Health, which established the Register Country of Legionellosis. The Guidelines for the prevention and control of legionellosis poses an operational tool to facilitate the detection of cases and to identify the strategic choices on preventive measures and control. As it can be seen by the Guidelines, chlorination is an excellent tool to fight legionella risk but in order to be effective it requires an appropriate dosage of chlorine [7-8]. The aim is keeping having potable water while eradicating the bacterium. In order to support this method, it is necessary to know the fluctuations of flow and speed in the water pipelines. The model that best fits to achieve this goal is a probabilistic model of end-uses as it is described in the next section.

2. Method

Since the 90s, a series of models that focus on the analysis of signal disaggregating the water demand in different end uses has been developed. It is referred to demand patterns taken into account by individual end-uses, which also consider socio-economic, cultural and climatic factors, derived from statistical and probabilistic assessments. Under this new approach, the Research Institute KWR Watercycle en Technische Universiteit Delft has developed a model based on end-use, the SIMulation of water Demand - an End Use Model (SIMDEUM), with the intent to avoid extensive campaigns of measurements [4]. Each final use is simulated with a rectangular pulse that is derived from a specific probability distribution for parameters such as intensity, duration and frequency of use. Pulses are conditioned by a chosen probability of daily use as well as by the usage patterns assigned to users. The modification of the latter leads in fact to obtain different patterns of demand. A series of statistical data and observations are the basis of this approach: type of users, number and age; types of use of buildings; types of end-use; user habits and spatial distribution of utilities.

2.1. Pattern

The daily patterns are habits of users, in terms of hours of operation and use of the various end uses. Because there is not in the literature a detailed description of the daily schedules in which the various water-demanding devices are put into operation, even if it is possible to define generic bands, the usage times are usually considered according to the user's presence in the building. Therefore, it is essential to know the daily habits of users, and describe them through the most likely times of their activities. Of course, these activities are related to the type of user, the day of week, the seasonality and must be represented taking into account that there are some times when their probability of occurrence is greater than others are. The probability distribution usually adopted is the normal distribution: for each type of activity is assigned a probability of occurrence within the day and the result is a sequence of cdf (cumulated probability distribution) on the time axis. The behavior of the individual user is instead represented by a random distribution, and the comparison of the latter with the cdf of the activity defines the pattern of that type of user.

2.2. Users and end-uses

The end uses are all water-demanding equipment usable in a building, depending on its intended use. The end uses directly affect the given frequency, while the different types for each use are related to the parameters of intensity and duration of the event. It explains the need to distinguish between the different categories of users, or the person or group of people that drive the different end uses, which have different characteristics and habits. The frequency, the intensity and the duration must be defined for each end use. The choice of the quantitative data is a function of the type of equipment, the type of building and the purposes for which they are used. The frequency F is the number of uses per person per day, and it is described by a discrete statistical distribution, preferably the Poisson distribution. The use of the Poisson distribution is motivated by the fact that it has only one parameter easy to

determinate. However, it must be emphasized that for some uses it is preferable to use a negative binomial distribution, when there is a higher frequency with the sampling variance, which can exceed the average. Instead, for the parameters of the intensity I and duration D there are adopted different probability distributions, depending on the equipment in use and the measured data, if they are known.

2.3. Simulation of the model

The data collected on the daily pattern on the users and the end-uses are the inputs to the model, which must be simulated in order to obtain the final data on water demand. The steps are: define the characteristics of users and their daily patterns; choose the end-use and collect their technical data; determinate, for each use and each user, the frequency of use; determinate for each frequency, their duration and intensity; calculate usage times and finally the value of demand as follows:

$$Q = \sum_{k=1}^M \sum_{j=1}^N \sum_{i=1}^{F_{jk}} B(I_{ijk}, D_{ijk}, \tau_{ijk}) \quad (1)$$

$$B(I_{ijk}, D_{ijk}, \tau_{ijk}) = \begin{cases} I_{ijk} & \tau_{ijk} < T < \tau_{ijk} + D_{ijk} \\ 0 & \text{else} \end{cases}$$

where:

j : counts all users from 1 to N ;

k : counts all uses from 1 to M ;

i : counts the daily occurrences for final use from 1 to F_{jk} , or the frequency of use for each user j and use k ;

D : pulse duration [s];

I : intensity of the pulse [l/s];

τ : time of arrival of the pulse;

D_{ijk} duration for each user k , each user j -th and the i -th occurrence;

$B(I, D, \tau)$ function equal to I for the time between τ and $\tau + D$, nothing in the rest of the time.

Q : total water demand, the result of the sums for all M uses, N users and F occurrences [l / s].

This obtained value in output is the result of a single pattern of demand, and then it is necessary to perform multiple simulations to obtain different patterns of use. Moreover, the value obtained is only one possible outcome, being the stochastic process.

3. Case study

The beginning of the Santa Lucia's Foundation activities dates back to 1960, when under a different name, the facility was dedicated to assisting veterans of World War II. In those years, the concept of rehabilitation, in its modern sense, was still virtually unknown. It starts, thus, an innovative process, fueled by the growth of ideas, initiatives and new methods, giving rise to the early functional rehabilitation programs, social reintegration and employment of the disabled, sports therapy. In the 80s, the Directors of the Foundation promote intensive research, by dedicating a portion of its budget to finance projects for the study of neurolesions. Not only Italian scientists participate in qualifying this reality. The issues and research results have been published in scientific journals having international dissemination [9-10-11]. On 7 August 1992, the Ministry of Health and the Ministry of University and Scientific and Technological Research, for their continuing commitment devoted to clinical activities, research and educational grant to the Santa Lucia's Foundation recognition of the Institute of Hospital Care Scientific, National Hospital Survey and High Specialization for the Neuromotor Rehabilitation and Neurosciences.

The Hospital Foundation is characterized by a modern and technological six-storey building, with a total area of over 30,000 square meters. The Roman Hospital, immersed in the natural oasis between the Via Appia and the Via

Ardeatina, meets the most modern organizational, technological and quality requirements. Each floor of the building has got 53 inpatient beds at the highest technological level, in rooms of 46 square meters with a private bathroom and a gym of about 400 square meters dedicated to fisiocinesiterapia. The hospital, highly specialized for the recovery and functional rehabilitation, has got 325 beds accredited by the National Health Service, of which: 293 beds for inpatient; 32 day hospital beds plus 17 solvent beds. The Foundation is characterized by a large basin for storage and treatment of water resources to the second basement. From there the water is pumped up to the ground floor by through a lifting system, where it is distributed in every point of the water network. Then through vertical water pipelines the water reaches the upper floors. For the schematization of the water network of the hospital, it is possible to use the commercial software EPANET 2.0 [1], spread widely, that is able to diversify the hot water network with its recirculation system from the cold water. In the schematization each unit hydro demanding must be considered in order to provide an assessment of the velocity of the water in the network most likely possible.

4. Data required for the application of the model

For the assessment of water demand of the Saint Lucia’s Hospital it is shown and adapted the model built in "Characterization of water demand through modeling end-use" - PhD Thesis in Environmental Engineering - XXIV Cycle - 2012 of Mrs. F. Caglioti for a residential case study of Latina. For the definition of users and the modeling of the daily pattern and the probability of use of the resource it is assumed that the study area is the Hospital of Saint Lucia in Rome.

Table 1.

Doctor’s activities	Mean (h)	St. Dev. (h)
Starting hour of medical visits	10	0.5
Ending hour of medical visits	12	1
Starting hour of intra-moenia activity	15.30	0.5
Ending hour of intra-moenia activity	17	0.5
Time out of Hospital	20	0.5

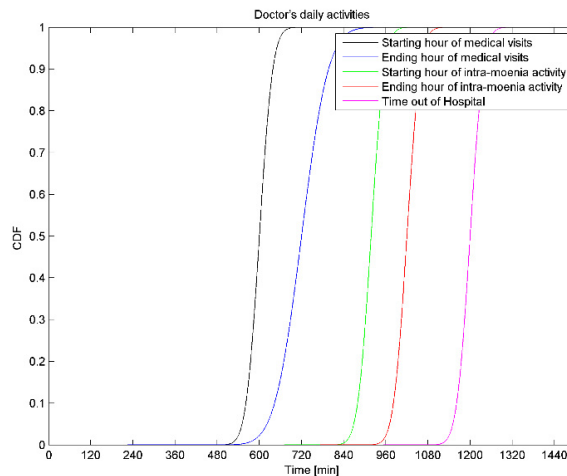


Fig. 1. CDF of the daily activities of the doctor user

Therefore, we can identify the following types of users: the doctor; cleaners; nurses; patients and visitors. For these types of users are defined the patterns of water demand. The daily pattern are generated according to the

stochastic process of the non-homogeneous Markov chain with three states. By adapting the Markov process in this case, the states are defined as follows: State 1: present active; State 2: absent; State 3: Present but not active.

To the probability of transition from one state to another is assigned a normal distribution with the mean and the variance parameters assumed according to the activities carried out by these types of users. In the table below there are shown the mean and the variance of the normal distribution of the doctor's daily activity. The related normal distribution is represented in the Fig. 1.

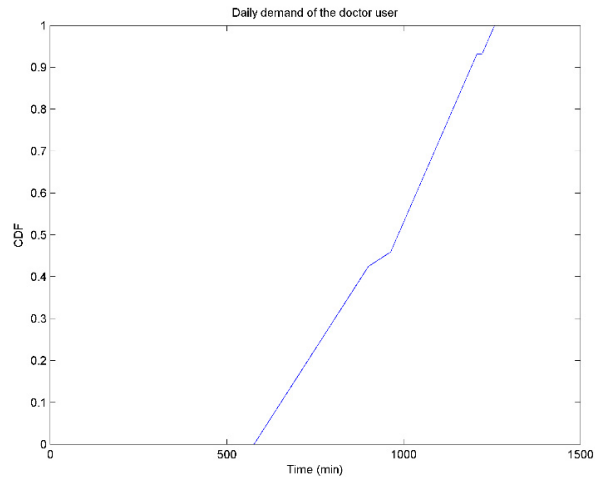


Fig. 2. CDF of the daily demand of the doctor user.

Then the terms of the transition matrix are obtained from the probability distributions derived from the data reported above in tabular form, and are compared with the random probability (U) that is generated by Monte Carlo method.

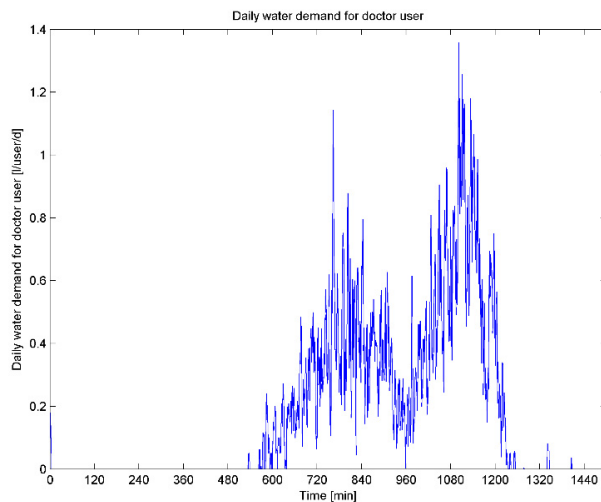


Fig. 3. Daily water demand for doctor user.

The generation of random numbers $U \in [0,1]$ allows you to have many possible status conditions. To assign the user status (S) at that instant is used an algorithm that compares the position of the n-th distribution of U with the probability distributions of the different activities. The status S so generated constitutes the pattern users in the time interval considered. The water demand of one type of user, both relative to each end-use and the total, can be calculated for different time step. For each type of user they also can be made more simulations in order to generate a wide range of evaluations. In the following figures (Fig. 2, 3) there are represented the results of 100 simulations for different uses for the doctor user.

The last figure (Fig. 4) shows that for the 22,5% of the total simulations the daily water demand for the doctor user is about 200 l/d.

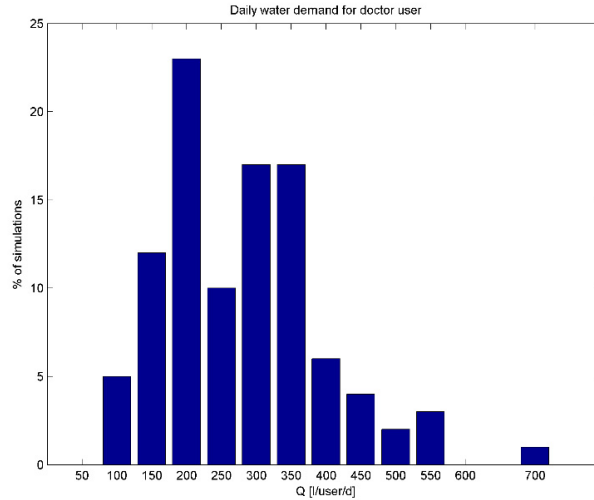


Fig. 4. The percentage of daily water demand for doctor user obtained by 100 simulations.

5. Conclusion

The problem of Legionnaires' disease in hospitals is present and heard both in Italy and in Europe. Several scientists were involved at the international level both to prevent the problem both to solve it. Among the various methods available in the literature, the chlorination is one of the most effective and easy to adopt. The idea behind this study is to provide a tool to control the chlorine dosage at each point of the water network hospital. In fact, through the knowledge of the speed and of the flow at each point of the network it is possible to obtain levels of chlorine and determine whether the legionella risk is high or not. This is achieved through the application of a probabilistic end-use model to the hospital water network schematized in Epanet 2.0 [1]. This model follows closely the activities of all users of the 'hospital, such as doctors, patients or cleaners. The schematization of the hospital's water network suggested in this article may provide an excellent tool for monitoring of water systems by legionella risk. The method illustrated above will be shortly implemented and validated by the measured flow data through the linking within the water network of two different flow meters.

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