Future Trends in District Heating Development

Authors: Tymofii Tereshchenko, Natasa Nord,*

Affiliations:

Department of Energy and Process Technology, Norwegian University of Science and Technology (NTNU), Kolbjørn Hejes vei 1 B, Trondheim 7491, Norway

*E-mail address: tymofii.tereshchenko@ntnu.no. Phone number: (+47) 92553322.

Abstract

Purpose of review: This article describes challenges that should be overcome towards implementation of low temperature district heating (LTDH). The trends in development, operational issues and legislative framework were revised.

Recent findings: The new substation design with solutions to avoid legionella bacteria issue, improved network topology and control strategies, opportunities of LTDH for buildings under various renovation stages and construction year were identified as the most crucial for the transition to 4th generation district heating (DH). Importance of heat load aggregation to avoid peak load issue in the areas with low energy buildings (LEB) and solutions for transition from high temperature to low temperatures in the DH network have been shown.

Summary: The findings indicate that there is a huge potential for achieving low carbon society and improvement in energy efficiency under transition to LTDH. The solutions for transition from high temperature DH to LTDH exist, however they need good policies and market availability to be implemented.

Keywords: Low-temperature district heating (LTDH), Low energy buildings (LEB), ZEB, future trends in DH development

1. Introduction

District heating (DH) is a technology helping in the decarbonization of society. The starting point in DH development was in US in 1880s. Three distribution technologies have been developed from that time [1]. Various energy sources have been employed and their number increases from year to year. These days the predominant number of DH systems are based on

3rd generation principle. However, active research is ongoing on 4th generation of DH. Fig. 1 shows different generations of DH distribution technologies and their potential regarding utilization of renewables.

Development of DH technology

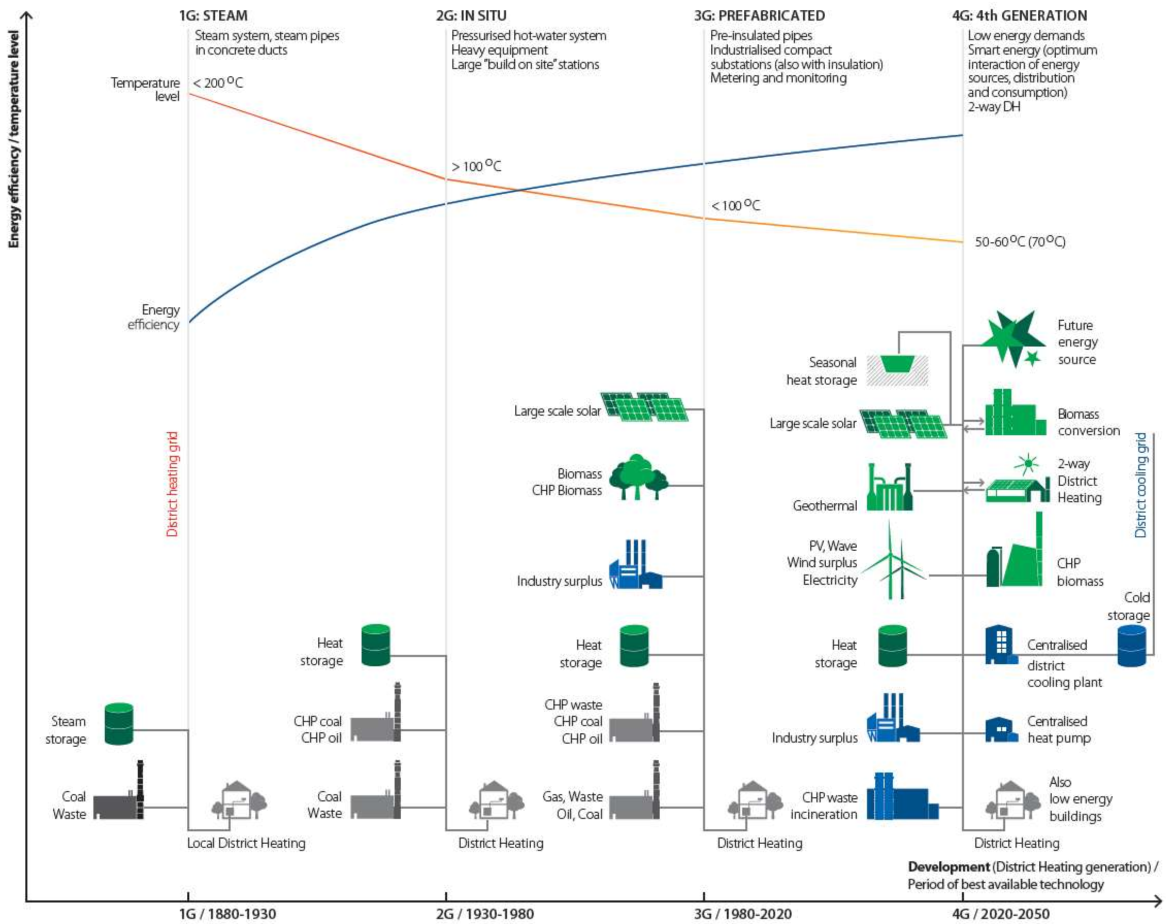

Fig. 1 Illustration of the concept of 4th Generation DH in comparison to the previous three generations [2••]

The term 5th generation is already on the table and described as a "smart" element that can ensure security and stability of the network with great penetration of small scale renewable energies. The concept aimed to provide heating, cooling and electricity to the urban area and has the ability to expand as the city grows [3]. In spite of the fact that some researches are mentioning the 5th generation as a concept for city development, the 4th generation is not established yet and all the effort will go to it implementation over the next decades. Therefore, this review article aimed to describe all the challenges that DH industry faces these days on the way to 4th generation of DH.

The development of 4th generation DH is essential to the implementation of Smart Energy Systems to fulfil national objectives of future low-carbon strategies as well as the European 2020 goals [4••]. With lower distribution temperatures and ability to utilize renewable energy sources (RES), this technology helps in recycling of low-grade heat from industrial processes. The DH systems exist in different schemes and stages across Europe. Mainly, the northern, central, and eastern EU countries leading the market with the greatest amount of heat supply from DH networks. In Scandinavian countries, DH systems cover up to 90% of the residential heat demands [5]. A number of recent studies come to the conclusion that DH plays an important role in the implementation of future sustainable energy systems. However, the same reports also emphasize that the present DH system must undergo a radical change towards LTDH networks supplying LEBs as well as becoming an integrated part of smart energy systems [6]. It is expected that the use of conventional fuels will reduce and the share of RES will increase by improving energy efficiency and by reducing the impact of the DH systems on the environment and the human health [7, 8]. Hence, the technology challenge is to consider all these new market conditions, such as lower heat demands in new buildings, low temperature levels for integrating RES, and higher efficiencies at low temperatures in almost all energy conversion plants [9]. Two scenarios are foreseen for the future of DH systems in Europe. First is the improvement of existing systems and the development of next generation of DH systems, with higher efficiency and lower costs, as well as the expansion of the heat sources' range with conventional and RES. The second scenario is the refurbishment of old and less efficient systems by new technologies towards hybrid systems with better performance [5]. One of the major challenges will be to provide heat with low temperatures in existing buildings [10].

In this paper the DH technology challenges are summarized and discussed. The rest of the article is organized as the following: Section 2 presents challenges with future heat load; Section 3 discusses temperature levels; Section 4 defines role of prosumers in the DH system and future energy sources; Section 5 deals with operational issues in LTDH network; successful applications of LTDH are collected in Section 6; questions regarding pricing and business models are enlighted in Section 7; and finally, Section 8 present general conclusions of this review.

2. Future trend in DH load change

The heat demand challenge arises from the fact that future buildings will have lower heat demands according to the near zero energy requirements in the European energy performance directive [11]. Furthermore, buildings which undergo major renovation should be upgraded to meet minimum energy performance requirements. All this means that in the near future the number of very efficient and passive buildings will increase, creating very miscellaneous loads of the DH demand side [12]. With the introduction of zero energy building (ZEB) and passive house concepts, the DH companies, as heat delivers, have faced issues with low annual energy use and high periodic peak load from such buildings. LEBs have significantly lower energy demand, typically 25–50% less, than conventional buildings [13]. Further, the heat load profiles over the year generally decrease and become smoother as a result of the energy renovation in existing buildings [14]. It is worth to notice that reducing the heating demand in DH network goes against the effectiveness of the DH generation side, which depends upon the density of heating demand [15]. In the one hand it is a positive trend towards decarbonization of the building sector, in another hand it is "the headache" for the DH companies, since low annual heating demand decreases effectiveness of existing energy generation units and, in turn, increases the quantity of more expensive peak heating for such buildings. ZEN buildings and new developments creates peak loads in the hours with high cost for DH production. Therefore, finding methods for moving peak loads and reduction of high cost of energy generation is becoming essential. Some papers dealing with solutions for peak load shaving suggest to utilize building mass as energy storage [16-19], while the other consider other types of available storage systems [20-24], application of demand side management (DSM) [25, 26] or innovative control strategies [27•-29].

Load aggregation is important for energy planning, particularly when it comes to the areas with ZEBs. Diverse typologies of real customers results in different coincidence factors [30], meaning that building areas in different parts of the country will have their own aggregated load profile. Simultaneously, the share of currently existing buildings in the building stock is expected to remain high for many years [6]. This implies that existing areas will develop itself in a mixed building stock with variety of building types. A proper load aggregation is vital for future development of DH and several studies could be highlighted [31, 32].

3. Issues in DH temperature levels

The temperature reductions in the DH networks are limited by the demands and technical requirements in existing buildings. In houses or commercial buildings these limitations are generally set by either the domestic hot water (DHW) requirements or the design of space heating (SH) installations [33]. The 4th generation of DH implies the employment of low temperature SH systems with the supply temperature of 40°C and the return temperature near to the temperature of 20 – 22°C. Simultaneously, it may be possible to use 40 – 50°C supply temperature for DHW. In that way, the temperature level of the DH supply to the buildings can be as low as 45 – 55°C [2].

A number of demonstration projects have proved that the DH supply temperature at slightly above 50°C can meet the end-user's SH and DHW demands, in properly designed and operated DH networks and in-house installations [34, 35]. Floor heating is an alternative to radiators for SH, with an average supply temperature just a few degrees above the indoor temperature [2]. The advantage with floor heating is lower requirements for supply temperature, while the disadvantage is slightly higher return temperatures, compared to radiators. A case study performed in [36] concluded that the supply temperature for floor heating of about 30°C with approximately a 3K temperature drop is enough to maintain an even temperature of the heated area. The results of other recent studies indicated that there is a large potential to lower the DH temperatures in the areas with existing single-family houses [37, 38]. For the buildings constructed in 1930s the average heating system temperatures could be lowered to approximately 50°C/27°C, while changing the radiator system. Simultaneously, the typical existing Danish single-family houses constructed in 1900s can be heated by temperatures below 55°C/35°C for large parts of the year [39]. Typical single-family house built in 1970s and recently still without any renovation measures can be heated by LTDH with 50°C/22°C, while with renovation the temperatures could be lowered [40].

The DH temperatures can be lowered further if the DHW is heated through a combination of DH and electricity. This is also referred as ultra-low-temperature DH (ULTDH). In this case the SH systems are the limiting factor with regards to temperature reductions. For example it may not be possible to lower the supply temperature to 40°C in old buildings where the heat loss is high and the heating elements are small [33]. The temperature cascading is one of the ways for transition from existing DH systems to LTDH systems [41, 42•]. The lower the supply temperature, the greater the potential to integrate low-grade heat sources with higher degree of monetary savings and reduction of environmental impact [43].

4. Energy sources and prosumers

The development of DH will move from current hierarchical and fossil fuel dominated large scale structure toward future decentralized, multiple renewable and waste heat sources dominated small structure [44]. Currently a number of solutions for decentralized heat generation are available on the market. Solar collectors, heat pumps (HP) [45], and micro CHPs are the technologies commercially available and ready for installation. Simultaneously, LTDH makes more advantage of geothermal plants, utilization of excess heat from industrial processes by heat recovery and flue gas condensation [34, 46]. Higher integration between electric power and heating systems into smart energy systems develops possibilities for new heat sources in hours when the electricity power is low, promoting HP technology for heat generation [9].

A new player comes to the DH market that is called prosumer. The prosumers can produce and consume heating [47]. The prosumers can be either existing residential and non-residential buildings or new LEBs, with available excess energy from IT centers, supermarkets and industrial applications. There are different approaches for the prosumer connections, depending on the DH network temperature level, delivered heat temperature level, and building requirements. Prosumer may deliver their heat into the supply or return line. Export of excess heat from the cooling machines (CM) to the DH network are shown in Fig. 2.

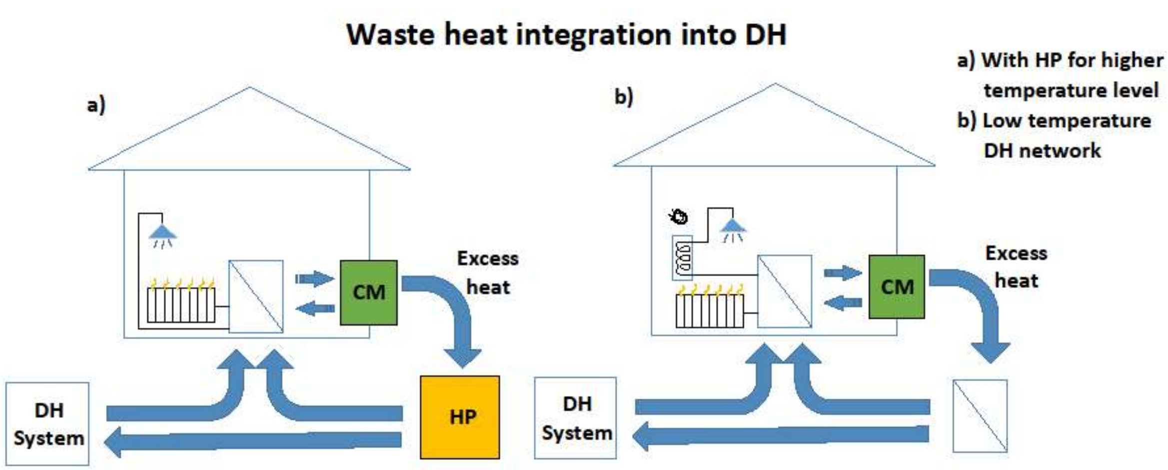

Fig. 2 DH and prosumer

Under the case a) Fig. 2 it is assumed that the DH network and buildings need higher temperature and therefore a HP is necessary to increase the temperature of the prosumer heat to the required temperature level. In the case b) Fig. 2, the excess heat is directly exported to the DH grid, while buildings may have possibility to increasing the temperature level, by including an electric boiler.

Despite of all the potential described of heat energy export from prosumers, this concept has also drawbacks that creates new challenges to overcome. The presence of prosumers could, for instance, induce higher or lower differential pressure among the customers reached by the flow from the prosumer. The supply temperature and the velocity in the pipes might also be affected [48]. In addition, both prosumers and renewable centralized systems need a tailored financial model to attract private small, medium, and big investors [12]. At the same time, there is a huge potential for possible prosumer contributions in areas with mixed building stock [49]. A number of papers are devoted to heat prosumer concept from the technical point of view. Analysis of energy sources, storage systems, and technical aspects about the transition to LTDH, could be found in [47, 49-51].

5. Operational issues in achieving LTDH

Currently identified barriers in achieving LTDH consist of demand side limitations, legionella issue, substations faults, and by-pass flows in networks [52].

Legionella bacteria and new substation design

One of the challenges in achieving LTDH is to be sure that there is no hazard due to legionella growth. Artificial aquatic systems are easily colonized with Legionella, which is the causative agent of Legionnaire's disease. Temperatures in water below 50°C and water stagnancy are considered the main factors that promote the growth of Legionella [53]. The problem of Legionella in DHW systems clearly needs to be addressed in advance of the implementation of LTDH and ULTDH. In general, the Legionella treatment solutions include thermal treatment, chemical treatment, physical treatment, and other alternative methods [54••]. Some articles describe methods how Legionella bacteria could be treated to reduce risk of contamination, while other describe approaches for substation design [55]. For example, employment of supplementary heating devices, so that the temperature of DHW can be boosted is found to be useful to reduce contamination risk. Another method is to limit the total volume of DHW use and heat the DHW locally and instantaneously, thereby reducing the risk of stagnancy as much as possible [56]. Further, by using substations without storage of DHW at the end user and pipes with only a small volume between the heat exchanger and the taps, the hot water volume is so small that the potential problem with Legionella bacteria is minimized [57]. A system with decentralized substations and low return temperature was investigated in [53]. The comparison of different types of substations with LTDH supply is presented in [58] and with ULTDH can be found in [56].

New substation design is also necessary when it comes to introduction of prosumers. The development of bidirectional substations that allows heat energy import and export is required. Well-functioning substations and building heating systems are a key towards low return temperatures [59]. It should be mentioned that the achievement of a low return temperature in the DH system is still a challenge [60]. The Swedish study on a number of substations in operation showed that analyzed return temperatures are still higher than expected and three out of four customer substations displayed temperature fails [61]. Therefore, new methods suggesting new design solutions arises [62, 63]. Various design of substations for decentralized solar energy export are discussed in [64], while analysis of operation under low temperature distribution is discussed in [65].

Improvements in the DH network

In traditional DH network design, the pipe lengths between the heating plant and different consumers vary. The consumers close to the plant have larger available differential pressure, whereas the consumers away from the plant have smaller available differential pressure. In an uncontrolled pipe network, the pressure profile in the system would lead to a higher water flow distribution through the consumers close to the plant and insufficient water flow through the consumers located far away from the plant. To overcome this, valves are installed in the network to increase the flow resistance until the required flow to fulfill consumer's heat demand is achieved [54]. Unlike the traditional network, a topology based on reverse return network [66] could be reliable solution to implement in LTDH. This would equalize the pressure differences between the supply and return pipes, which reduces the impact in case of malfunctioning valves [67]. When the network heating demand becomes low, the required mass flow rate is reduced accordingly. When there is no draw-off in non-heating season, the DH supply water is bypassed and flows back to the network return line without any cooling, leading to increase in return temperature and heat losses. This network performance degradation is particularly relevant for LTDH and DH supply to sparse areas. To keep low network return temperature, it should be avoided having the DH supply water directly mixed with the return water. Several solutions have been highlighted to eliminate the service pipe bypass [68, 69]. Different typologies of grids in terms of number of pipes have been suggested in [70-72].

Monitoring and fault detection

Energy utilities that care about the accuracy of billing information and the quality of services delivered to customers need to monitor the substations in order to detect faults in the instrumentation [73]. Faults in substations resulting in insufficient cooling of the supply temperature have different causes. The errors in control chain are rather common in comparison to heat exchangers and system design [1]. The controller tuned at a certain operating condition may be unstable when operating condition changes in large range. For example, the operation instability of DH substation may occur at the high primary supply temperature, if the controller is tuned at low primary supply temperature [74]. Incorrect energy meter data may happen if any of these components malfunction [75].

With the development of Information and Communication Technology (ICT), automatic meter reading systems have been installed in DH applications. These gives advantage in such issues like for fault detection, control optimization, and identification of heat load patterns [76]. Heat metering plays a key role in smart heating systems. Since such meters allow thermal energy accounting and enable a reliable measurement of energy use, they are becoming very effective tools to improve energy efficiency and promote energy savings in a smart way. Furthermore, they provide a real-time operational rating and diagnosis of the plant and the building units with overall real-time optimal control of energy systems [77]. A comprehensive review on the topic of smart heat metering can be found in [78]. Bidirectional LTDH networks requires an improvement in operation efficiency. This can effectively be achieved with agent-based control. This control system successfully coordinated various heat and cold sources and facilitates in keeping the network temperature around a specified set point [79].

6. Examples of implementation of LTDH

Successful examples of implementing the LTDH systems have been already demonstrated in a number of projects. The most representative cases are gathered in this section. LTDH that is developed in Denmark, such as Lystrup [80, 81]; LTDH in Sønderby and Lower temperatures for existing systems in Middelfart [54]. SSE Greenwatt Way development project was established in Slough in the UK [82, 83]. Several projects in Germany: Energy efficient DH network in Ludwigsburg; Residential area with geothermal heating and cooling in Wüstenrot; Geo-solar local heat supply for residential area “Zum Feldlager” in Kassel [54, 84]. Future DH solution for residential district were developed in Hyvinkää, Finland [85, 86]. Planned LTDH for a green neighborhood, Brøset, Trondheim, Norway [87, 88]. Innovative project in the field of LTDH and cooling networks in the district of “Suurstoffi” in Central Switzerland [89].

7. Price and business models

Financial part in project development continues to be a limiting factor in progress towards renewable society. DH pricing is a core element in reforming the heating market, because the heat price and price for the heat export will influence decision on energy source and active customer role. Unfortunately, the existing DH pricing methods, cannot simultaneously provide both high efficiency and sufficient investment cost return. The lack of specific economic incentives to reduce costs and also the market dominance of existing suppliers are perceived as a significant barrier to the development of new products. For this reason, the interaction between LEBs and LTDH should enable new business models, since one of the issues is how to push existing customers to purchase green energy exported by prosumers. It is obvious that CHPs and other mature technologies were in operation over one century and are proven to be reliable. These technologies have low generation cost at high generated volume, however, it is opposite when it comes to prosumers. The fluctuation of solar irradiance and seasonal variation are factors decreasing the reliability of solar energy. Therefore, the governmental subsidies should provide incentive to promote collaboration between existing DH customers and prosumers. Moreover, an effective pricing mechanism could also assist in further energy saving and CO_2 emission reduction, because it is essential to promote sustainability of DH systems [90]. The development of feed in tariffs should take place, since nowadays there is limited legislation framework to promote prosumers’ operation.

The idea of heat trading is not new, but only now, when small-scale heat production has become more common it has arisen again. Liberated heat trade can be carried out by the same principle in local DH network as electricity trade [91]. The interest of DH companies for buying excess heat from industry is clearly higher than for acquiring heat from small-scale production. However, customers want to sell heat if the required investments can be covered in a reasonably short period of time. In order to make heat trading possible, the DH need to be opened [12]. Both the industry and the municipality can benefit economically from this cooperation. The ZEBs are still not involved in such DH system due to relatively small portions of heating energy that could be supplied to the energy grid and this is the main challenge that DH companies have to manage in the nearest future. Other obstacles are commonly organizational, how relation works between the parties and how the partners are organized. Openness and trust are crucial for a successful project. It is also necessary that the involved parties focus on the total benefits of the co-operation, instead of their own and that both parties benefit. The contract should be stable and long-term. It is crucial that the contract period is at least as long as the investment's payback period. It is vital to involve experienced personnel and to educate the personnel responsible [92]. The generic activities that create value in a value network are also divided into three areas: 1) To increase members of the network by promoting it to new customers, as well as to manage contracts; 2) To deliver the service and charge for the use of the network; 3) To manage the network's physical and technological infrastructure so that the service can be offered [93]. Even if the core product – transmitted heat energy – is homogeneous, it is necessary to acknowledge that there are differences between DH solutions that are important to take into account in a description of DH's commercial context. Some of these are: how heat is produced, ownership structure, a DH company size; the product portfolio; and geographical location (growth region, flexibility map for fuel markets or regional networks) [94]. For the successful implementation of prosumers concept, an appropriate pricing model for demand response services will have to be developed. DH price should represent real cost requirements which mean that it should establish balance between different customers regarding their heating requirements, stimulate the cost effective behavior of the customers, and provide good balance between the fixed and variable cost. Existing DH pricing methods, such as the cost-plus pricing method and the conventional marginal cost pricing method, cannot simultaneously provide both high efficiency and sufficient investment cost return [95]. The cost-plus pricing method is often used in regulated DH markets, while the marginal-cost pricing method is commonly utilized in deregulated markets [96]. The energy savings companies (ESCO) might be involved in DH operation as a part of business model like it was done in Austria [97], which implies that a third party company has access to DH business as well.

8. Conclusions

This paper revised obstacles and challenges in achieving 4th generation of DH. Various aspects of distribution technology, operational issues and legislative framework have been enlighted. The review indicates that there is a huge potential for achieving low carbon society and improvement in energy efficiency under transition to LTDH. New developments are achieved in substation design tied up with solutions how to avoid legionella issue, control strategies for efficient DH operation and peak load shavings. New low temperature RES are already on the market and prosumers are ready to deliver heating energy to the grid. However new pricing and business models are lacking to motivate DH companies for buying that heat. In general, DH industry is on early stage towards 4th generation of DH and big effort is required to decrease temperatures in existing DH networks and enable benefits of LTDH.

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This is ongoing project that aimed to find new control meghods and strategies for operation in LTDH networks. The solutions to avoid peak loads should be investigated.

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