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# A small geothermal project of low enthalpy in Bío Bío sand

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ABSTRACT: There are currently very high levels of air pollution in many cities in the centre and south of Chile due to mostly the intensive use of burning wood heating systems. It is found that the cheapest choice in terms of heating efficiency and price per kWh is a shallow geothermal system. Consequently, a small pilot geothermal project of low enthalpy was designed and built in order to provide an economical and non polluting heating system in the town of Santa Juana, Chile. A small 3.92 kW geothermal heat pump was connected with a net of shallow soil heat absorbers, which were buried 1.5 m in a non-plastic medium dense silt. Thermal properties of this fine deposit of the Bío Bío River, were obtained. Preliminary monitoring results have shown that this shallow geothermal system is able to sustain the interchange circulating water temperature at night to keep around 19°C indoors when the outside temperature is around 10°C.

## 1 INTRODUCTION

The current environmental situation in the south of Chile, especially during autumn and winter, is very serious due to high levels of air pollution. There are cities such as Talca, Chillán, Temuco, Valdivia, Osorno and Coyhaique where the high level of particulate matter PM comes mainly from combustion of wood fuel in household stoves. For instance, more than 93% of PM from firewood burning in residential sectors of Temuco corresponds to $PM_{2.5}$, which has the most serious health effects in human beings (Schueftan & González, 2013). Although there are governmental strategies to reduce the air pollution, they try only to mildly ameliorate and react to the problem rather than avoid it from its origin (DS 39, 2014). Recommendations such as the use of drier wood and brand new stoves are not really solving the problem (Schueftan & González, 2013, 2015).

$PM_{2.5}$ limit levels as day average in $\mu g/m^3$ have been stipulated as: good: 50; fair: 80; warning: 110; pre-emergency: 170; emergency: 250; health emergency: beyond 250. Available data from measurements since 2003 until 2012 shows that there has been a steady increase of $PM_{2.5}$ and $PM_{10}$ in the cities mentioned above. For instance, in 2012 Temuco had worse records than Beijing in China, with 7 (Temuco)/2 (Beijing) warnings, 10/6 pre-emergencies and 9/7 emergencies, totalling 26/15 exceeding limit levels with a peak value of 956/886 $\mu g/m^3$. This air condition is leading to serious health problems in the population, especially babies and old people. More details of the current air pollution situation coming from household heating in Chile can be found in Celis *et al.* (2004), Silva & Arcos (2011), Schueftan & González (2013, 2015), among others.

It is worth pointing out that changing the current polluting practice of household heating for a non-polluting one will save also thousands of millions of dollars spent every year on breathing and lung health programmes. Moreover, it would save the indiscriminate cut down of local native forest, which can take hundreds of years to grow. Other advantage it will be the elimination of the fire danger when household stoves and chimneys are out of control burning housings, and even wounding and killing people. Furthermore, wood combustion requires constant and regular supervision, from delivery, cubic meters of dry storage to the insertion of previously chopped pieces into the stove several times during each day.

It will be shown that one of the best possible solutions for this environmental problem is the use of a heating system which is not only clean but it uses energy stored in shallow ground, which is provided by the sun, hence renewable. It has to be pointed out that this geothermal system does not need a hot ground as in very deep borehole systems. In the following, an example case of low enthalpy geothermal system is presented. The idea is to show the possibility of developing this system in a small scale project without requiring large excavations such as expensive well systems or large areas for pipe systems.

## 2 LOW ENTHALPY GEOTHERMAL PROJECTS

Low enthalpy geothermal projects are relatively new in Chile with no so many examples. They have been

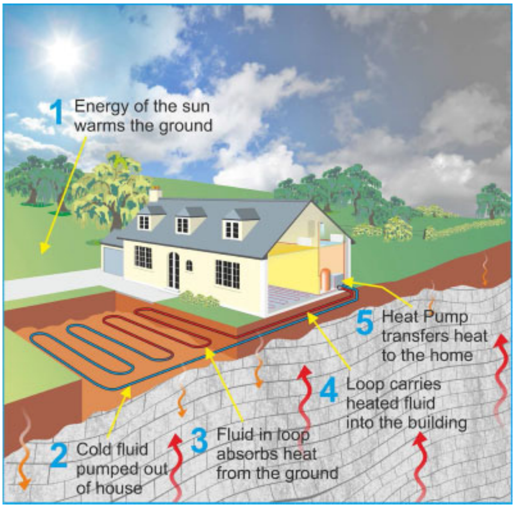



Figure 1. Sketch of shallow heat from the ground (Geological Survey from Ireland 2015).

expensive and mostly based on boreholes for large buildings for schools, hotels and universities.

The aim of this project is to make accessible to much more people a non-polluting heating system, using renewable energy, therefore, reducing the extensive use of polluting burning wood. In addition, the solution has to be economically affordable and therefore low inversion and installation costs should be required as well as low or no maintenance cost. In fact, geothermal heating turns out to be the cheapest option according to the price of heating per kW as shown in Table 1, where prices are presented for different options of heating fuel and type of heater.

Some of the advantages of a geothermal system are the possibility of invert heating to cooling, no negative environmental impact, no need for large physical space for the installation and equipments, no visual impact, low or nil maintenance cost and high energy efficiency and COP around 4 (*e.g.* Inalli & Esen, 2004; Omer, 2008). The latter means that a heat pump needs 1 kW of electricity to obtain around 3 kW from the ground to generate 4 kW of thermal energy (hot water), resulting in a coefficient of performance COP = 4. Figure 1 shows a sketch of extraction of heat using shallow collectors with depths between 0.8 and 1.6 m instead of deep wells of up to 100 m, which can be prohibitively expensive due to complicated boring, installation, operation and maintenance. The fluid circulating in the buried collectors is water with ethylene glycol to avoid freezing.

This fluid when passes through the heat pump is compressed to in this form extract the heat coming from the ground.

During autumn and winter the shallow ground temperature can fluctuate between 5 and 15°C, and after passing through the heat pump the fluid temperature drops significantly and it is put back in the collectors to recover extracting again the ground temperature.

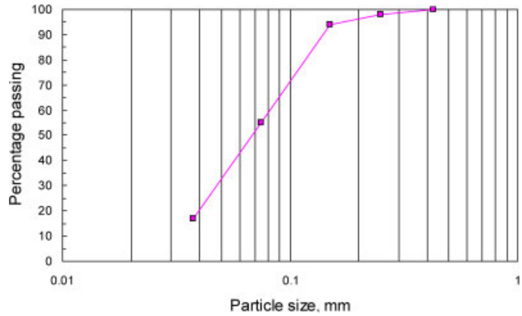



Figure 2. Grain size distribution of soil around the collectors.

But in other closed circuit, the fluid of the heat pump towards indoors can be distributed from 25 to 45°C in the same way as a central heating will do. That is, through floor, wall or ceiling radiators or even for shower hot water.

Similarly like in any other heating system it is important that the building insulation is sufficiently efficient to avoid letting the heating to leave quickly the rooms. Roof, windows, walls and floors should slow heating from dissipating to the exterior. It will be shown in the following that despite the semidetached housing not having adequate insulation, the proposed geothermal system works anyway.

## 3 SANTA JUANA PILOT PROJECT

### 3.1 *Ground properties*

Santa Juana is a town located 48 km south of Concepción, Chile. It lies next to the south bank of the Bío Bío River. The ground where the collectors extract the heat in Santa Juana corresponds to a fine material with around half of the particles having sizes smaller than 0.075 mm. Figure 2 shows the grain size distribution of the fine material where the row of collectors are buried.

The specific gravity of the soil particles is $G_s = 2.82$, revealing the presence of basalt, the maximum and minimum void ratios are $e_{max} = 1.09$ and $e_{min} = 0.63$ and the water content is $w = 16\%$. Although the soil surrounding the collectors is not saturated and the soil particles are very fine, the soil coefficient of permeability $k$ can be estimated by using the well known Hazen formula based on an effective diameter as $d_{10} = 0.031$ mm, resulting for a loose soil in $k = 10^{-5}$ m/s. For a dense soil, $k = 4 \cdot 10^{-6}$ m/s for $d_{15} = 0.035$ mm. Using the Kozeny-Carman formula with a grain shape factor of 6.4 for worn grains (see Figure 3), results in not so different values, $k = 1.8 \cdot 10^{-5}$ m/s for a void ratio of 0.9 (40% of relative density) and $k = 10^{-5}$ m/s for a void ratio of 0.7 (85% of relative density). Due to the large percentage of fine particles the soil classifies as low plasticity silt ML according to the USCS. But in fact, they can be treated as a fine sand since the particles do not have plasticity at all as can be observed in Figure 3.

Table 1. Cost of heating for different fuel and type of heater (Jahnke, 2014).

| Fuel, heater type | Energy price, \$[1] | Net energy, kWh | Efficiency, %[2] | Price heating, \$/kWh |
|---|---|---|---|---|
| 1 kg wood 20% humidity, old stove | 150 | 4.28 | 60 | 58.4 |
| 1 kg wood 50% humidity, old stove | 150 | 2.42 | 60 | 103.3 |
| 1 kg wood 20% humidity, modern stove[3] | 150 | 4.28 | 80 | 43.8 |
| 1 kg wood 50% humidity, modern stove | 150 | 2.42 | 80 | 77.5 |
| 1 kg wood 20% humidity, old chimney | 150 | 4.28 | 15 | 233.6 |
| 1 kg wood 20% humidity, old salamandra[4] | 150 | 4.28 | 35 | 100.1 |
| 1 kg sawdust pellets, modern stove | 215.25 | 4.50 | 85 | 56.3 |
| 1 kg liquid gas without gas release outside | 1044.44 | 12.87 | 100 | 81.2 |
| 1 kg liquid gas with efficient gas release | 1044.44 | 12.87 | 80 | 101.5 |
| 1 kg liquid gas with not so efficient gas release | 1044.44 | 12.87 | 60 | 135.3 |
| 1 kg catalytic gas without gas release outside | 1088.89 | 12.87 | 100 | 84.6 |
| 1 lt ethanol without gas release outside | 1400 | 5.49 | 100 | 255.1 |
| 1 lt kerosene without gas release outside | 730 | 9.58 | 100 | 76.2 |
| 1 lt kerosene with efficient gas release | 730 | 9.58 | 80 | 95.3 |
| 1 lt kerosene with not so efficient gas release | 730 | 9.58 | 60 | 127.0 |
| Electric radiator, kWh normal price | 81.33 | 1 | 100 | 81.3 |
| Electric radiator, kWh overconsumption price | 112.34 | 1 | 100 | 112.3 |
| Heat pump, kWh normal price | 81.33 | 1 | 300 | **27.1** |
| Heat pump, kWh overconsumption price | 112.34 | 1 | 300 | **37.5** |

[1] \$ is for Chilean pesos, \$720 = 1 US\$, \$760 = 1 Euro.
[2] energy effectively used for heating, considering losses.
[3] modern double chamber air-tight steel stove.
[4] steel and iron old model of wood heater and cook stove.

Geologically speaking, the sand has been transported by the Laja and Bío Bío Rivers from the Antuco volcano erupted materials 200 km upstream in the Andes Mountains. This alluvial deposit is composed mainly of basalt and feldspar, for that reason its colour is predominantly grey, although there are also particles with other colours such as brown and white as previously described by Ayala *et al.* (2015) for coarser grain size distributions. Figure 3 shows an amplified photograph of the soil grains extracted at 1 m depth next to the collector's trench.

The Santa Juana fine soil thermal conductivity $\lambda$ was measured using a manual thermal analyser KD2 PRO (DECAGON, 2008; ASTM D 5334, 2008). This instrument also allows the measurement of the thermal resistivity $\rho$, heat capacity $C$, thermal diffusivity $d$ and soil temperature T as shown in Table 2. The measured average thermal conductivity of the soil was 0.551 W/m/K with a standard deviation of 0.067 W/m/K. This range of values is later on used to design the geothermal system, for example the number of absorbers and the heat pump capacity as a function of the air temperatures encountered. No analysis of the variation of $\lambda$ nor the other geothermal properties have been performed in this preliminary study. It is a matter of further studies the assessment of the effect of variations due to for instance, saturation degree, humidity and density on the soil geothermal properties.

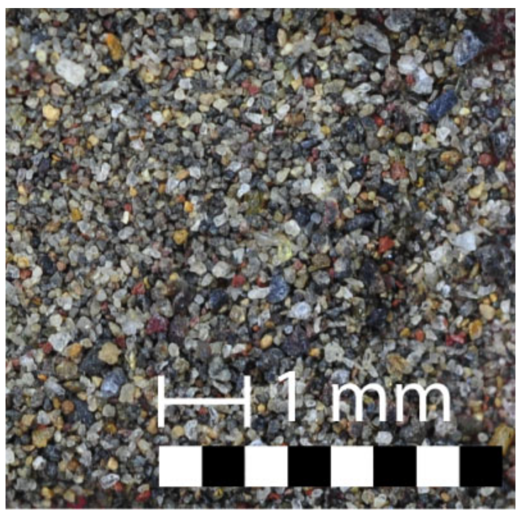



Figure 3. Image of soil grains of Santa Juana (courtesy of Mauro Poblete from LGM, UCSC).

### 3.2 *Heat absorbers*

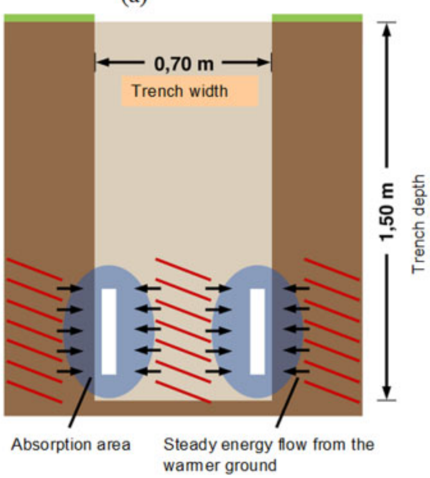
What makes this geothermal heating system technically and economically possible is the use of shallow absorbers or collectors as shown in Figure 4(a). In addition, the land surface needed for the installation of absorbers is much smaller than for usual pipe type absorbers (*e.g.* series, parallel, slinky), being around a seventh of the usual land surface. Figure 4(b) shows that the width and depth of the trench excavated should be 0.7 m and 1.5 m respectively. In cases where the excavation sides are unstable, for safety reasons, a shore system should be implemented.

Table 2. In situ measurements of soil thermal parameters (cega.ing.uchile.cl and BBSolutions).

| λ, W/m/K | ρ, mK/W | $C$, J/g/K | $d$, mm$^2$/s | T, °C |
|---|---|---|---|---|
| 0.577 | 173.4 | – | – | 10.58 |
| 0.573 | 174.6 | – | – | 10.78 |
| 0.531 | 188.3 | 1.541 | 0.345 | 10.98 |
| 0.453 | 220.9 | 1.447 | 0.313 | 11.24 |
| 0.610 | 164.1 | – | – | 10.40 |
| 0.610 | 163.8 | – | – | 10.54 |
| 0.500 | 200.2 | 1.474 | 0.339 | 10.35 |
| 0.519 | 172.8 | 1.643 | 0.316 | 10.80 |
| 0.675 | 148.1 | – | – | 10.44 |
| 0.464 | 215.6 | 1.819 | 0.255 | 10.44 |
| 17.62 | 5.675 | 77.43 | 0.228 | 0.29* |

*frozen soil.

(a)




(b)

Figure 4. a) Collector model used (www.geocollect.de) and b) trench dimensions with collectors' position.

The backfilling of the trench should be carried out carefully to not damage the collectors or the pipe connections. Each collector module is around 0.9 m long, 0.35 m high, resulting in approximately 0.63 m$^2$ of flat interaction with the surrounding soil. This collector design allows an efficient absorption of the ground energy due to a much larger absorption surface than the flat 0.63 m$^2$. The absorbers are made of polypropylene and filled with a mixture of water and glycol, which is the heat transmitter and transports the energy from the ground to the heat pump. For more details see the Handbook (2014).

(a)

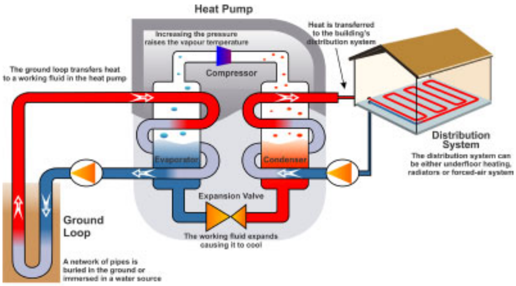
(b)

Figure 5. a) Front view of the semidetached housing of the Santa Juana project and b) excavation with geothermal collectors at the back.

A semidetached housing of 50 m$^2$ divided in two floors without a proper thermal insulation was used as the pilot project as shown in Figure 5(a). Additionally, Figure 5(b) shows the excavation dug in Santa Juana with 30 collectors, which corresponds to 3 kW of power. Note that the land surface needed by the collectors is 16 m$^2$, which is much less than other horizontal type of absorbers such as pipes, which will need around 140 m$^2$.

### 3.3 *Geothermal heat pump*

A geothermal heat pump, also called Ground Source Heat Pump GSHP, is a system that transfers heat from the ground for heating as well as to the ground for cooling and also can supply warm water to buildings. Figure 6(a) shows a general diagram of a geothermal heat pump. The cycle starts when ground heat is captured by a buried absorption circuit as explained in the previous section. Then the circulating fluid reaches the heat pump where by means of applying high pressures in a compressor this fluid vaporises, increasing significantly the temperature. This higher temperature




(a)

(b)

Figure 6. a) General diagram of a heat pump and b) heat pump installed in Santa Juana project (www.neura.de).

is transferred to another fluid inside the building distribution network or second internal closed cycle, for example in wall radiators, underfloor or ceiling radiators. To close the external cycle, the vapour flows to a condenser where then passes through an expansion valve that expands the fluid, sending it back cool to the absorption circuit where the cycle starts again.

The horizontal closed ground loop arrangement used in this project brings the fluid that captures the geothermal energy from the ground to the electric heat pump shown in Figure 6(b). This small 3.92 kW heat pump system makes possible that the circulating water-glycol mix with a consumption of 0.97 kW of electricity can result in a COP = 4.0. This value needs to be verified by measurements of heating load divided by the sum of the power input to the compressor, water-antifreeze solution circulating in the pump and condenser.

During six months of monitoring a geothermal heating system with pipe absorbers, Inalli & Esen (2004) found that the average COP value increased around 0.2 for 2 m depth buried pipe collectors respect to other buried at 1 m. In this project 30 collectors were chosen for 1.5 m depth according to the available soil thermal

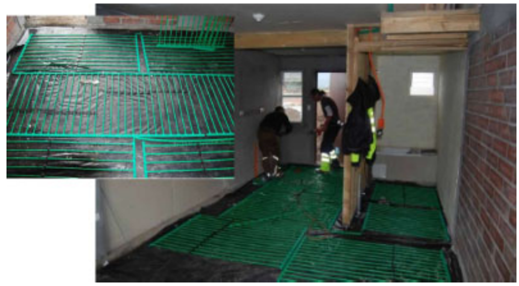


Figure 7. Mat radiation system installed below the floor and ceiling (www.ewktec.com).

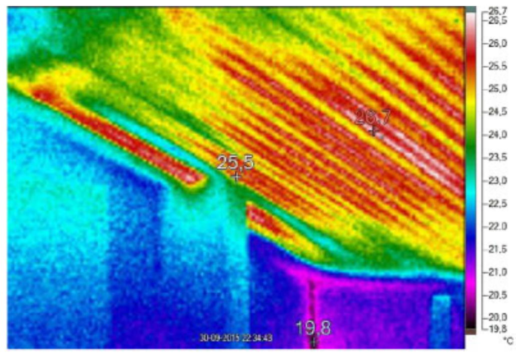



Figure 8. Infrared photography of inclined ceiling (courtesy of Francecs Ferraro from UCSC).

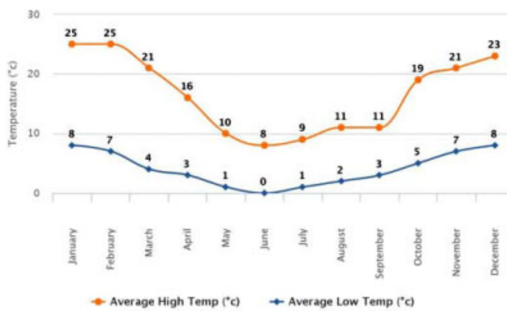



Figure 9. Average maximum and minimum temperatures in Santa Juana (http://www.worldweatheronline.com).

conductivity (see Table 2). For these conditions the systems works properly until soil reaches −13°C, below that temperature the soil is unable to have enough time to recover and transfer heat to the absorption system. This was determined following recommendations by VDI 4640 (2010). However, further research is needed to assess the buried depth effect on the panel type absorber as a function of soil thermal properties and number of collectors.

### 3.4 *Radiation system*

A system of mat radiation under the floor and in the ceiling has been adopted as shown in Figure 7. The

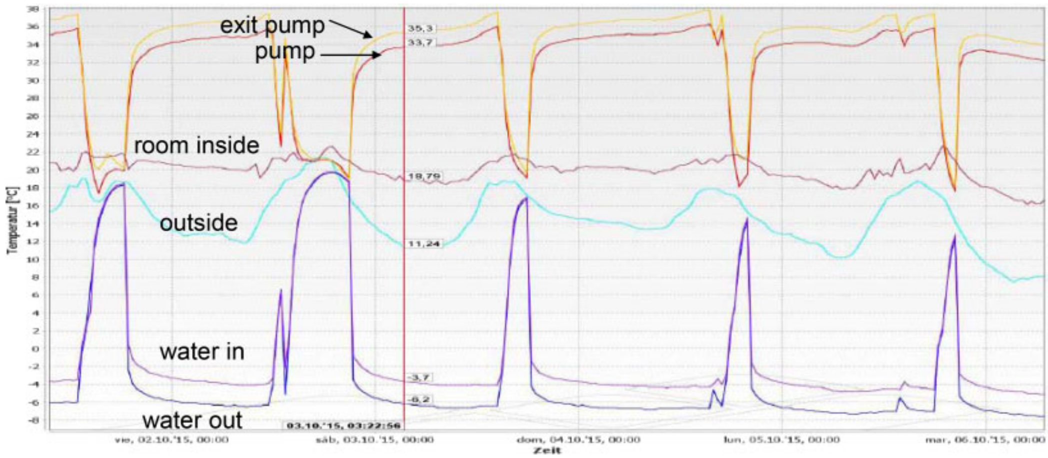



Figure 10. Typical output from monitoring system temperatures.

system is cheap and uses lower temperatures of radiation, around 25°C. It makes the warmed fluid to flow in parallel small pipes. It is flexible and easy to install even in inclined surfaces as the ceiling for example (see Figure 8). A more uniform heat radiation is generated, giving a better comfort when compared with fixed wall radiators which irradiate higher temperature heat, but tend to send it to the ceiling along the walls.

Figure 8 shows an infrared photography of an inclined part of the ceiling. Note the lines showing the presence of warm fluid at 25°C in the small pipes of the thin mat inside the inclined ceiling.

### 3.5 *Preliminary results*

Figure 9 shows the air average maximum and lower temperatures in Santa Juana. It can be seen that the autumn and winter months between May and August are the ones when more heating is needed. Below zero temperatures are rare and summer months of December to February would need cooling.

Figure 10 shows temperature results obtained from sensors installed in the geothermal system. The monitoring system has been installed to measure the temperature of circulating water within the absorption and heat pump piping as well as outside and indoor temperatures. Preliminary results have shown that the shallow heat extraction geothermal system can sustain the interchange circulating water temperature down to −6°C at night to keep around 19°C indoors when the outside temperature is around 10°C.

These are preliminary results and more extreme temperature conditions are needed to assess the geothermal system performance. However, what is clear from the data in Figure 10, it is that the system recovery capacity is quite fast.

## 4 FINAL COMMENTS

A new low enthalpy geothermal heating system is proposed for Chilean small housing developments. This pilot project in Santa Juana aims to offer a solution for not only a cheaper and efficient way of heating but also to reduce the extensive use of polluting burning wood risking the lives and health of people and saving extinction of local native forest. The geothermal properties of the fine soil in Santa Juana are adequate for extracting heat for the averaged temperature conditions encountered. Research is needed to study possible variations of these property values due to variations in saturation degree, soil density and soil humidity. The combination of specific components and devices made possible the set up of an efficient low enthalpy geothermal system for a small scale project. The Santa Juana project opens the possibility for the development of similar geothermal systems around the centre and south of Chile. However, it is suggested that like in this case, there should be always, at least at the beginning, a pilot project with enough time for monitoring to take into account possible thermal ground differences as well as environment and construction conditions.

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