Measurement and modelling of a multifunctional solar plus heatpump system from Nilan. Experiences from one year of test operation.

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Abstract

A multifunctional solar and heat pump unit from Nilan has been installed in the Performance Test Facility (PTF) at DTU Byg Denmark. It is part of the IEA Task 44 cooperation. Multifunctional means in this case: Hot water, Air heating, Ventilation, Air heat recovery, Air filtering and Floor heating. Nilan units, with additional air cooling and CO_2 control, are also available.

The unit has been in operation for more than one year. The aim has been to stress the system operation to different conditions in the lab, to learn more about the performance, but also to find possible improvements especially concerning advanced control. The operation into extreme states of high hot water demand and low air ventilation rates, has also been done to develop and validate a TRNSYS system model. The model was developed and validated for the first period of operation mainly winter and early spring conditions. Now the system has been in operation during all seasons and a full year model could be developed and validated. The model also includes new possibilities for solar collector loop and heat pump operation control.

1. Introduction

A multifunctional solar and heat pump unit from Nilan has been installed and tested in the Performance Test Facility (PTF) at DTU Civil Engineering, Lyngby Denmark. It is part of the IEA Task 44 Solar and Heat Pump cooperation. Multifunctional means in this case: Hot water heating, Air heating, Ventilation, Air heat recovery, Air filtering and Floor heating. Nilan Compact units, with additional Air Cooling and CO_2 control, are also available.

A system drawing of the compact solar and heat pump system from Nilan is shown in Figure 1. The installation in the house is shown in Figure 2. So far the system has been tested for ventilation air heating and hot water production (shown within the solid line frame in Figure 1). The unit has two heat pumps one larger for the floor heating connected to a ground source brine loop to get heat from the soil around the house and one smaller heat pump loop for hot water and ventilation air heating, the latter taking energy from the ventilation air leaving the house. The unit also has a built in ventilation air to air heat recovery unit that works passively without heat pump interaction, se Figure 3. This heat exchanger takes potential evaporator energy from the small heat pump loop, but is very cost effective by first preheating the incoming air before the final heating by the smaller heat pump. This makes the modeling, measurements and testing quite complicated. Many heat flows are involved and several operating modes. The heat pump loop also has a double condenser design, se Figure 3, that means that a standard heat pump model can't be used. The evaporator in the exhaust ventilation air flow also extracts latent heat from the moisture in the indoor air leaving the house. This significantly increases the possible energy extraction but causes short operating modes of defrosting especially in the winter period. The latent heat extraction gives a lot of condensate water during a day. This is no problem in a house installation if prepared correctly, but had to be solved in the lab in a reliable way. But by measuring the condensate it is also possible to estimate the latent energy flow during a test.

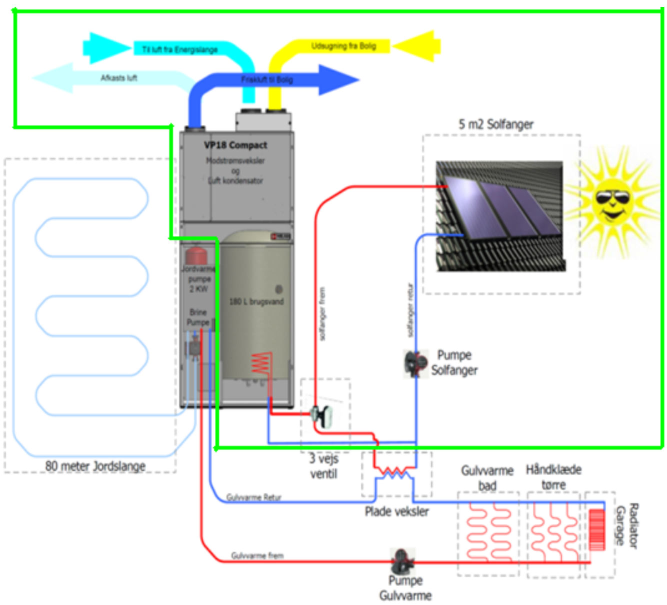

Fig. 1. A system drawing of the compact solar and heat pump system from Nilan [3]. So far the system has been tested for air heating and hot water production (within the solid line frame). The unit has two heat pumps one larger for the floor heating and one smaller for hot water and air heating.

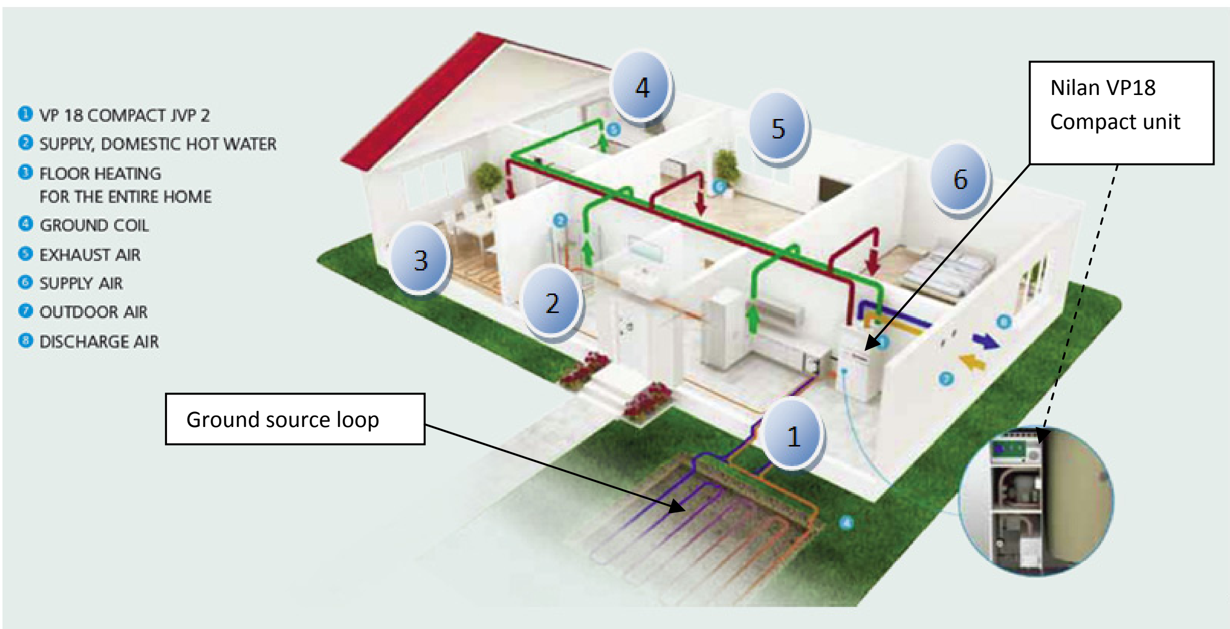

Fig. 1. A typical residential house installation as it was depicted in the Nilan broschure with the unit installed without the solar thermal part [3].

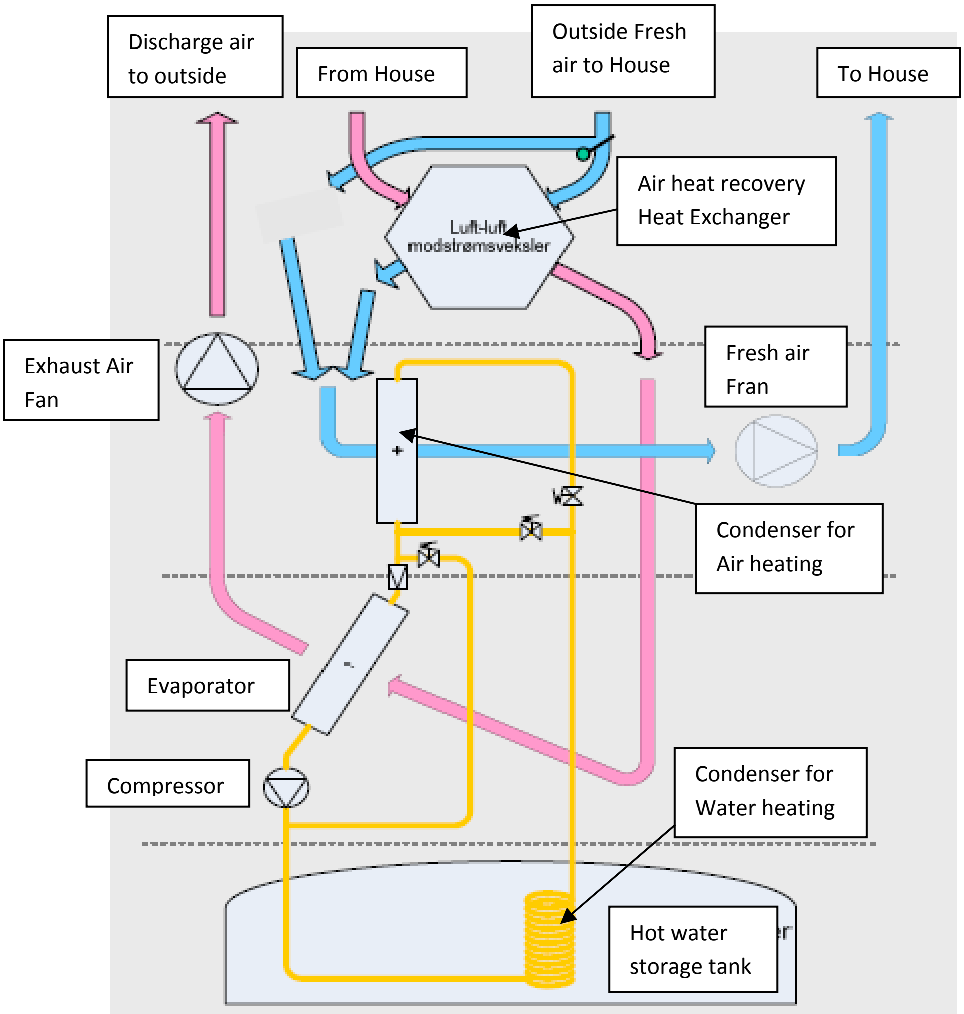

Fig. 3. A diagram showing the quite complex flows of air and refrigerant.The single evaporator and two condensers in the heat pump loop can also be seen. Note also the inner refrigerant loop for defrosting of the evaoporator using the superheated refrigerant after the compressor.

2. Operating experiences

The Nilan Compact VP18 unit has been in continuous operation, since the start of the project in the autumn 2010, with very reliable function. The only maintenance has been normal change of air filters and an upgrade of the internal defrosting control. When testing at low air flow rates and high daily hot water demand, as was done in the lab for shorter periods, to validate models, the evaporator can get full of frost easily and the defrosting control becomes critical. An upgrade of the control solved the intermittent operating problem, we had in the compact unit for test.

In this critical situation the air to air heat recovery already takes most of the sensible heat from the exhaust air to preheat the incoming air and only latent heat in the air is left to hot water production. Latent heat “down to” condensation in the evaporator is no problem as there is a water drainage system in the heat pump unit. But when continuing to extract latent heat by solidification of condensate to ice the air flow is slowly reduced through the evaporator and the capacity is restricted more and more in a negative loop and defrosting is finally needed. One recommendation from the testing is therefore to control the defrosting by measuring the air flow pressure drop over the evoporator. Now the defrosting is controlled by measuring the evaporator temperature with a standard mechanical thermostat, similar to a refrigerator control unit.

As the evaporator energy to the heat pump, comes from the exhaust air flow leaving the house, the house ventilation rate setting is critical for the heat pump capacity and also the COP. A relatively high setting of the minimum air flow, that is accessible to the house owner, is therefore recommended. A normal customer will be dissatisfied when the electricity consumption goes up, if as he reduces the ventilation air flow too much in winter to “save energy”. Even direct electric backup heating elements can cut in and increase the consumption quite dramatically in this operating situation of too low air flow. If the air tightness of the house has deficiencies, it is very likely with extra low ventilation flow settings, during the winter.

One special design of this unit is that even during air heating mode the superheated refrigerant gas after the compressor, is still passing the water heating condenser coil in the tank and will release some thermal power that compensates for heat losses from the tank. This saves backup electricity use.

The collector loop operation was not fully reliable in the beginning of the test period, The loop lost pressure and finally stopped, as the pump had not enough fluid to work. This was caused by a misunderstanding by the installer of the new overheat protection principle by partial evaporation. An air vent valve was placed at the outlet of the collector in a classical way for installers. But this released steam during partial evaporation operation in the collector loop and fluid was lost slowly. The collector loop had to be refilled frequently. This operation mode is extra common for this unit, as the collector loop and heat pump control was not coordinated. They are two separate control units. The only connection was that they measured temperatures in the tank at different levels. This meant that the typical situation was that the heat pump could charge the tank at full power at the same time as there was full power from the sun. The tank was quickly reaching to the maximum temperature and both heat sources were stopped. All solar energy available could not be utilized during the day and the electricity consumption and operating time of the heat pump was unnecessary high.

It is therefore one possible improvement of the unit, to integrate the solar controller into the advanced heat pump controller. The heat pump operation can then be delayed, when solar heat is available and the tank top is already charged enough for good comfort. This may need some kind of forecast control to really reach the potential improvement and give the best comfort to the user. The comfort is of course very important to maintain for most customers.

The solar collectors has been performing as expected when checking against Solar Keymark test data and modeling with the real operating conditions in the system. But the non optimal system control has reduced the possible operating time and the number of kWh produced over the test period.

2. Modeling of the compact unit

The validation of the simulation model was based on the condensing power in heat pump water heating mode, heat pump air heating mode and combined solar + heat pump water heating mode [2]. It is common to show model validation results by comparing temperatures but here the condensing power has been chosen. The purpose of showing the power output instead of temperature is because this is closer to the final need and purpose of the simulation model which is to analyse energy savings. It is much harder to have a good match in power output than in outlet temperature. When plotting temperatures it is often forgotten (or hidden for the reader) that an inlet temperature level is most often already known from measurements and the model just gives the temperature rise or difference that can be a few degrees. This is not so often realized. Therefore an effort was made to avoid this intermediate “unsharp” step in validation. This results though in that the modelled output seems less accurate at first.

The three operation modes are depicted in Figure 4. The numbered areas (1 ,2 and 3) indicate the condensing power when the system operates in domestic hot water heating mode. The rest of the areas in the graphs indicate the air heating operation mode. With a grey line, the calculated condensing power based on the monitoring data, is indicated for all operating modes. With a thin black line, the result is shown for the model, for total power to the tank during combined operation (heat pump plus solar thermal). The thick black line refers to the modelled condensing power, during air heating mode. As it can be observed the air heating part is simulated precisely by the model during the day [00:00-07:00, 11:00-12:00, 14:00-19:00, and 22:30-24:00]. For the water heating mode and the combined performance (area 2) within the dotted circle the model has high agreement with the reality. It is obvious that the model can follow the trend and also in some parts give precise values for the combined operation of the units. In the first hot water draw off though (area 1); despite that the model can follow the trend, the results are a bit higher. Furthermore the usage of average values for the Carnot fractional efficiency results in that the model is not being able to predict all the modes precisely, different convergence between simulation and reality can be seen in the three draw-offs.

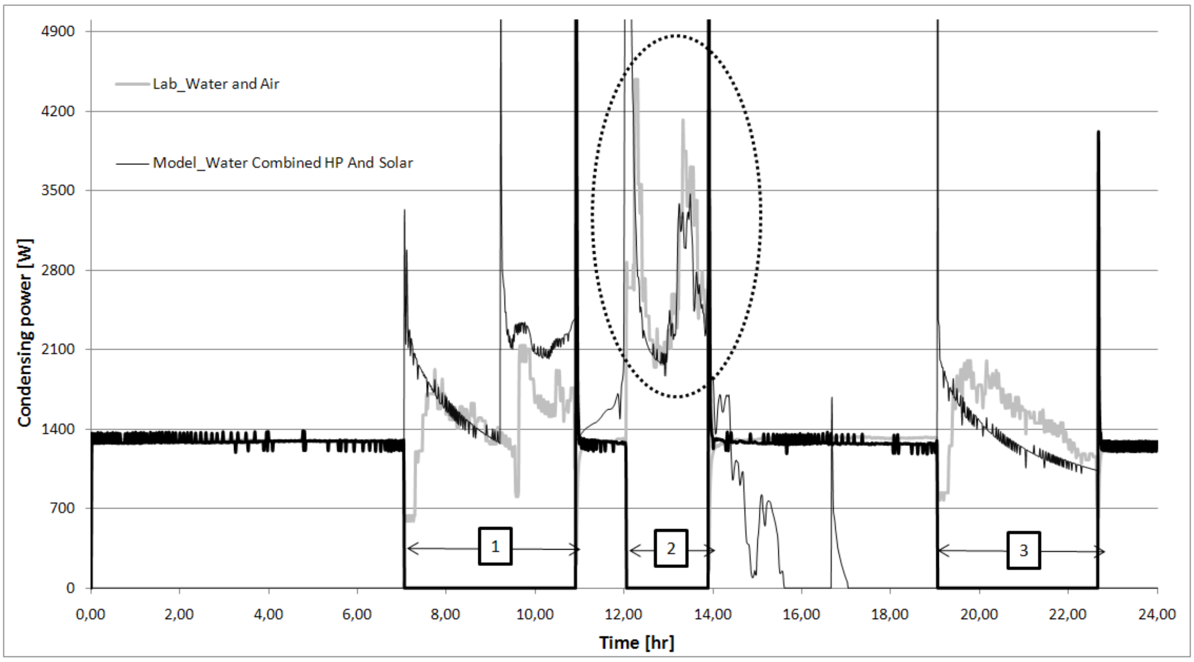

Figure 4. Simulation Model validation. Condensing power for air and hot water operation during a test day in March 2011. Both Model and Measurements are shown.

3. Simulation results

A system simulation model for a house with a Nilan Compact VP18 unit was developed in TRNSYS. The collector and heat pump model was first checked against lab tests, se figure 4, and was then used to generalize the test results to annual performance, under different conditions to see the influence and importance of some design and control parameters. This Simulation study is just in the beginning and the format for comparison of solar plus heat pump systems within IEA Task 44 has to be adapted later too. The main investigation here is to study possible improvements of the present non optimal solar plus heat pump control. Also the value in primary energy savings by adding solar collectors is of interest.

Figure 5 shows the difference in backup energy needed from the heat pump, with and without solar collectors, to meet a Domestic hot water demand of 100 l/day. Figure 6 shows the difference in Electricity to the heat pump.

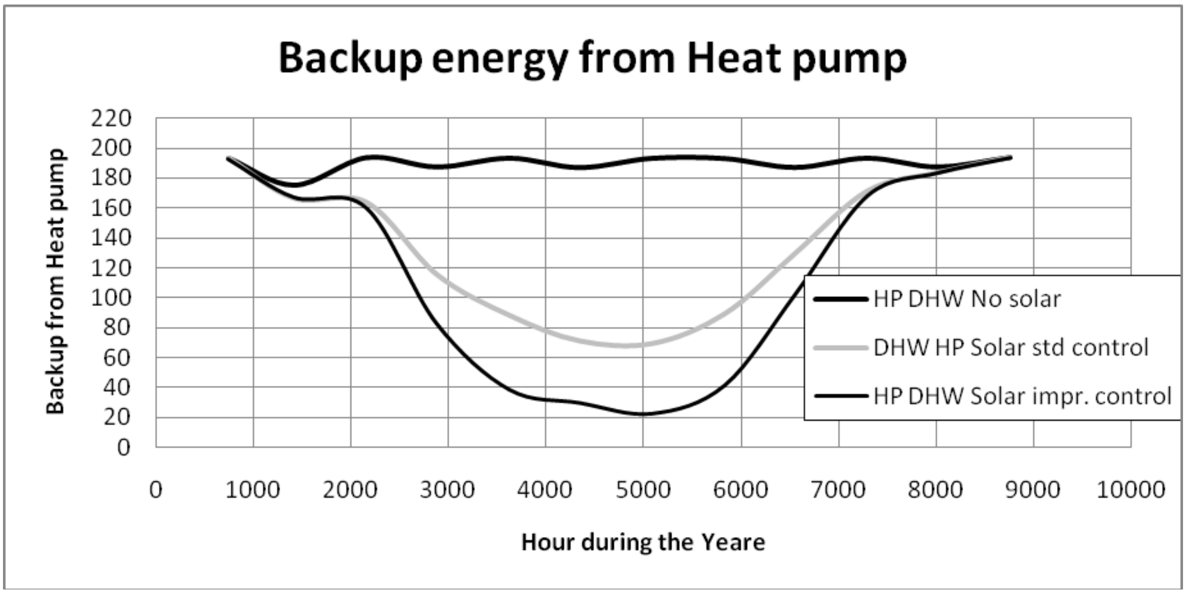

Fig. 5 Difference in backup energy needed from the heat pump to the tank with and without solar collectors and different control.

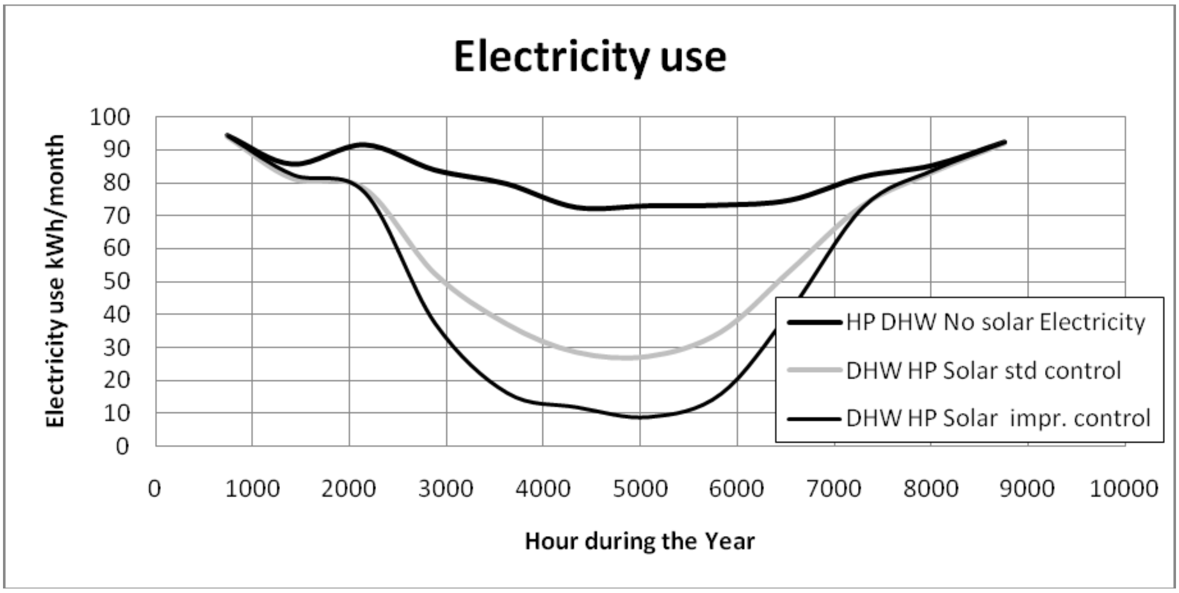

Fig. 6. Difference in Electric energy to the heat pump for hot water production with and without solar collectors and with different control.

It can be seen that the backup energy and electricity use can be reduced by around 35 to 40% by adding collectors and using a better heat pump control. This better control gives priority to the solar collector operation when solar energy is available during daytime.

In this study the possible further savings by forecast control is not investigated but can be an interesting option especially when variable electricity prices are available to the final electricity customer. Then the tank can also be used, to shift the heat pump operation time, to hours with lower electricity costs. In most climates the solar collectors produce most of the energy when the electricity prices are high during the day, giving an added value to solar.

4. Findings from Lab Tests and Simulations

The Nilan Solar + Heat pump Compact VP18 unit has been in reliable operation for more than one year. Only minor operating problems has occured, that could be upgraded by the manufacturer.

The test operation and modeling has shown that the control integration between the collector loop and heat pump is very important for efficient operation. Presently tank temperatures measured at two separate points are the only connection for control between the two systems. The heat pump can therefore charge the storage at full speed at the same time as the collector is running at full power. In the future forecast control will be very advantageous for maximum use of solar collectors, minimizing the electricity cost and minimizing the storage size. The match between the air flow or air exchange rate in the house and the air- plus hot water heating demand is also very important.

- A TRNSYS system simulation model has been developed and validated for the first period of operation, mainly winter and early spring conditions.
- The Nilan unit has been very robust and reliable in spite of the extreme states of operation tested.
- The installer education and awareness about the design of overheat protection of the collector loop can be improved.
- The ventilation air flow rate should have a relatively high minimum setting in accordance to the house design to avoid that the end user reduces the air flow too far.
- The heat pump control can be improved so that simultaneous operation of the solar collector and heat pump is minimized for hot water production.
- In the future weather based forecast control of the system can improve the solar savings significantly

References

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