Evaluation of a novel 3-pipe solution for hydronic heat distribution in passive-house standard apartment buildings

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ABSTRACT

The energy efficiency of new buildings in Norway has been steadily improved over the last decades, but with less heating, hydronic heating systems have adversely increased in price. Lessening electric power consumption in new buildings is an important part of the government's plan to de-carbonize, in which hydronic heating is a suitable alternative for direct electric heating. In this regard, a developer claimed to have found a potential cost-efficient hydronic solution in terms of investment cost. This solution is based on two measures, using the Domestic Hot Water (DHW) circulation loop to cover both DHW demand as well as space heating demand in the building, and significantly reducing the number of heat emitters. In this work, we studied the possible benefits and the issues associated with this solution and performed an analysis based on the following accounts, i) the distribution system, ii) indoor climate, iii) energy demand/consumption, iv) hygienic security. A newly finished apartment complex located in central Oslo is chosen for this purpose. Two apartments and the central heating are examined by inspection, experimental measurements, and Computational Fluid Dynamics (CFD) simulations. The distribution system is examined to confirm the alleged cost efficiency with a simplified cost calculation based on the BIM-model and the documentation provided by the developers. We estimated an additional cost of 67 NOK per square meter in comparison to direct electrical heating. The end user could also financially benefit from using less expensive district heating. Using fan-coils as main heat emitter in each apartment was found to produce satisfactory indoor climate, however, in one apartment it was found that poor planning sabotaged its intended function which negatively affected indoor climate. Additionally, we found a lack of measures to protect the DHW from Legionella-growth, which is a violation of Norwegian building code TEK17.

INTRODUCTION

In Norway, heating demand for new buildings has decreased considerably the last two decades. New, stricter regulations require efficient heat recovery, tightness, and insulation which minimize heat loss. With a lower need for heating, one might expect heating systems to decrease in scope and price, but the costs for hydronic heating systems have adversely increased in the same period. Rising costs for energy-flexible heating sources such as hydronic heat are perceived as problematic for the construction industry. Electrification of transport and industry is particularly an important part of the government's plan to achieve a 50 % reduction in non-quota emissions. To achieve this with existing electrical infrastructure, the power requirement in buildings must be reduced (Miljødirektoratet, 2020). In 2018, KMD (Ministry of Local Government and Modernisation) and DiBK (Norwegian Building Authority) proposed a change in building regulation. In which buildings over 1000 m^2 would be required to use energy-flexible heating systems that covered a minimum of 80 % of the heating demand, in comparison to the current 60 %. The reasoning for the proposal was to curb power jumps and large scale upgrading of grid infrastructure, which in turn could ease the transition to a fully electrified transport and industry. In practice, this would mean that all buildings over 1000 m^2 would be required to use hydronic heating systems. With this, it is possible to use several non-electric energy sources and energy-efficient heat pumps. DiBK's proposal received responses from a number of players in and outside the industry, of which some argued that investment costs and housing prices would greatly increase if the regulations were to be stricter (Revfem, 2018). Those in favour of the change are mainly energy, consultation and environmental organizations who stated that it would be necessary to relieve the electric-grid and make buildings more energy-efficient to achieve climate goals (NVE, 2020). The new regulation was planned to be put into effect 01/01/2019, but this was postponed indefinitely.

Background & Objective

The term energy flexibility is linked to an objective that a building should be able to be heated by means of different energy sources or by means of different energy distribution systems (Revfem, 2018). Most often, this means a hydronic heating system. Building regulations stipulate that buildings must in part be energy flexible. Nevertheless, large sections of Norway's new buildings use direct electric space heating, as the current requirement of at least 60% energy flexibility from TEK17 §14-4 does not completely exclude direct space heating (DiBK, 2017). The investment cost of hydronic heating is considered to be significantly higher than direct electric, and in order to achieve the best possible financial gain in construction projects, the cost-effectiveness of direct electric heating is often prioritized. However, the alleged benefits of direct electric heating have recently been questioned. Demand for electricity in transport and industry has increased significantly to achieve Norway's climate goals. With this increase, the price of electrical energy to consumers has also increased by 50% in the period 2016–2019, and the price is expected to increase further (Havskjold, 2020).

NVE (The Norwegian Water Resources and Energy Directorate) proposed changing the grid rent structure, so that households also pay according to the sizes of the power peaks (Torfinn. J, 2020). If the developer chooses direct electric space heating, it can for the above reason increase cost for the consumer, but it will potentially also give indirect societal costs as well. Andreas Bjelland Eriksen, advisor in NVE, estimates that for every 1 kW reduction in peak hour output saves 4,500 NOK in grid development costs (Havskjold, 2020). This means that consumers could experience higher grid rent as peak loads increase. In addition, it should also be considered that a portion of electrical energy in Norway originates from fossil energy sources, which in longer terms results in societal costs as a result of climate change.

In February 2020, consulting engineering firm Erichsen & Horgen presented a report examining the actual costs of hydronic heating systems, to find how it affected property price (Havskjold, 2020). The report concluded that hydronic heating is not a significant driving factor for total building-costs and did not necessarily affect housing prices as claimed. One specific cost-reducing solution presented in the report was a solution with a combined DHW and space heating system in apartments. The report mentions an apartment complex built by 'AF Gruppen' in which this type of solution had been used. The solution called 'direct 3-pipe system' (see Figure 1) can reportedly reduce investment costs, operating costs, space, and installation time for hydronic heat (Nørstebø, 2018) (Mathisen, 2019) (H. S. Kristofersen, 2019) (Kulvik, 2019). If such a solution could significantly improve on hydronic heating in respect to cost, it could have considerable significance for the entire industry as well as the proposed change in regulations.

In AF Gruppen's project «Dronninglunden», the contractor wanted to test an energy-flexible solution that could compete with direct electric heating (Figure 2) in cost per m^2 living space. A solution that uses less electricity for heating can provide benefits to consumers and society (BJØRHEIM, 2019).

This solution would also be combined with a simplified method for heat dissipation, where water-borne fan coil and underfloor heating in the bathroom alone accounts for the largest share of the heating. To date, no complete assessment has been made of this solution in terms of cost-effectiveness, consumer friendliness and hygienic safety. In this work, we investigate whether this solution can challenge direct electric heating on price, and possibly what experiences should be taken further when the solution is used.

The objective is to find if direct 3-pipe system combined with a fan coil satisfies current regulations and expectations, as well as whether the solution has led to reduced investment costs. In addition, it will be assessed whether the heating system is adapted to practical operation and use and how comfort is affected for the residents.

To investigate these issues, we study the following:

- <u>The distribution system</u>
  The solution for the heating system, direct 3-pipe system, is considered an untested method. It can reportedly provide savings on investment and operation. Does this also apply to Dronninglunden?
- <u>Heat emitter and indoor climate</u>
  A fan coil is used for heating and cooling the living units. What implications does this have for the end user?
- <u>Energy needs and consumption</u>
  How is the energy consumption of the apartments, and what degree of energy flexibility has been achieved?
- <u>Hygienic security</u>
  Questions has been raised as to whether the solution is less safe in respect to bacterial growth, is this correct?

To answer the above questions, measurements and numerical simulations are performed in two apartments at Dronninglunden. A simplified cost assessment is prepared based on data provided by the AF Gruppen, to analyse the alleged savings of the novel hydronic solution.

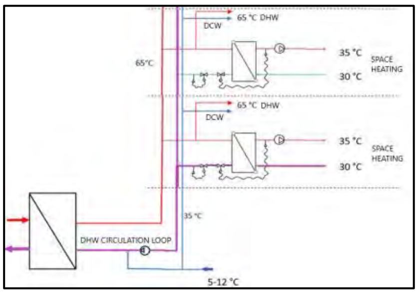

Figure 1: Example of direct 3-pipe system solution with underfloor heating as main heat emitter

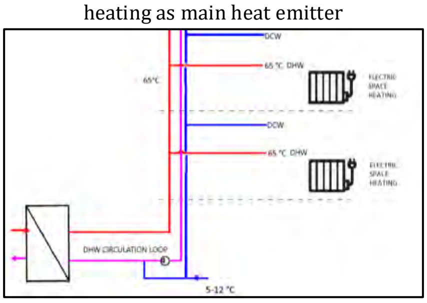

Figure 2: Example of a solution with direct electric space heating, which the 3-pipe solution is compared to in terms of cost.

METHOD

The distribution system

The cost assessment is performed using internal cost data made available by the contractor AF Gruppen. These values are compared with a corresponding estimate of direct electric heating in the same average apartment. The cost comparison between direct electric space heating and direct 3-pipe system is carried out with the following simplifications:

- The cost difference is assumed to be negligible in the primary circuit. Dimensioning and choice of solutions are comparable in both situations, with only a moderate reduction in pipe, pump and heat exchanger sizes.
- In both cases, the secondary network is approximately the same, with a moderate increase in pipe size with the 3-pipe system. Installation and material costs are assumed to be little affected by this difference in size and are then neglected in the cost assessment.
- The costs for bathroom cabinets with direct electric underfloor heating and hydronic heating are set equal. The technical director of the AF Gruppen was informed that their cabin supplier, Probad, gave the same price for cabins regardless of whether direct electric or water-borne underfloor heating was installed (Olsen, 2020).
- AF Gruppen's reported costs are assumed to be correct and are not extensively verified.
- Costs for piping at Dronninglunden are not documented by AF Gruppen. A CAD model (using Revit) for plumbing is used to calculate the total number of meters of pipe-in-pipe PEX. This is used in connection with the heat emitters in the apartments. "Norsk Prisbok 2019" is used to estimate the cost of materials and installation of said piping. (Norsk Prisbok 2019).

The simplifications of the cost-analysis are considerable, the resulting numbers should therefore be considered an estimate.

Heat emitter and indoor climate

Indoor climate field measurements

The selected measurements provide a basis for arguing for or against the use of a fan coil as a heat emitter. Q-Trak with thermal anemometer and probe, globe thermometer and thermography camera are used to perform the necessary measurements. In all measurements, the fan coil is set at maximum speed of 2.25 m / s. Noise is not analysed, as an earlier work had found no considerable noise issue (Tania Markussen, 2018). During the first inspection, the air velocities are measured at 6 points in apartment A-H0602 and at 5 points in apartment E-H0702, both on four different heights, see example in Figure 3. The measuring heights are presented and explained in Table 1. The lowest measuring height is 1.1 m, as the fan coil is ceiling mounted.

Table 1:Measuring heights during field measurements.

Height		Reason
1.1	*m*	Inside residence zone
1.8	*m*	Upper limit of residence zone
2.1	*m*	Mapping of the fan-coils airflow pattern
2,6	*m*	

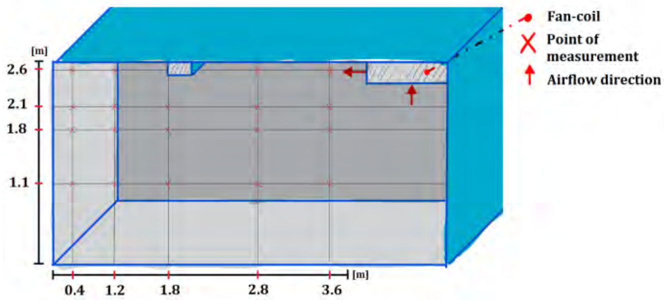

Figure 3: Sketch of heights and points of measurements in E-H702, resulting in a total of 19 measurements. (figure not to scale)

Air speed is only measured in the living room where the fan-coil is located (See Figure 6-Figure 9). This is to investigate presence of a coandă effect and to detect air velocities exceeding discomfort levels within the residence zone. Uncertainty calculations was made to find the sensitivity of temperature and velocity calculations. Measurements of air velocity are stated with an uncertainty of ± 0.016 m / s.

The air temperatures are measured at eight points in A-H0602 and at six points in E-H0702 at three different heights of .1, .6, and 1.1 m. This is to identify or exclude unpleasant vertical temperature differences. Measurements of air temperatures are performed with a Q-Trak connected thermal anemometer. The operative temperature is calculated with air temperature and mean radiant temperature. An anemometer connected to a Swema 3000 logger is used for measuring air temperature, and radiant temperature is measured using a globe thermometer connected to the PeakTech digital reading screen. A thermography camera is used to give an indication of coandă effect from the fan coil. The apartment is first cooled down, and then the fan coil is set on full heat. The resulting trail of heated airflow is then visualised using the device.

CFD simulations

We performed numerical simulations with CFD tool StarCCM+ considering air (steady incompressible turbulent flow) as working fluid. Two-equation (standard $k-\epsilon$) turbulence model is used to solve governing fluid flow equations with Reynolds Averaged Navier Stokes approach. CAD models of the apartments A-H0602 and E-H0702 were constructed in StarCCM + on a scale of 1: 1 (see Figure 4).

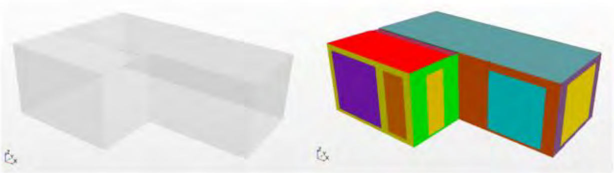

Figure 4 CAD, A-H0602 in StarCCM + from south-east direction.

A more refined mesh is constructed around the fan coil's intake and exhaust. Mainly around the separate ventilation exhaust and in the ceiling in front of the fan coil, up to the opposite wall as seen in Figure 5.

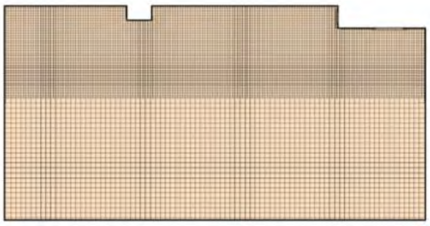

Figure 5 Plan from apartment E-H0702 to illustrate the mesh network with different refinements.

In apartment A-H0602, part of the fan-coil inlet is in the hallway, outside the CAD model. In apartment E-H0702, the entire inlet is in the model. This means that the former unit only has one out-flow as output in the file. The latter has both out- and in-flow as outputs in the file. Therefore, the mass flow in E-H0702 was assessed. Table 2 summarizes input variables for the apartments. Both apartments have extraction from fan coil as inputs in the files. Exhaust and intake are set as "velocity inlet" boundary condition (BC), which actively sucks air in or out of the room, where the intake has a negative speed. The exhaust is set as a "pressure outlet" BC.

Table 2: Calculated values used in StarCCM +

Parameters		A-H0602		E-H0702		
		Out flow	In flow	Out flow	Out flow	In flow
Area. A	m^2	0.08	0.06	7.9E-3	0.30	0.06
Velocity. v	$\frac{m}{s}$	Set as pressure outlet BC	2.25	Set as pressure outlet BC	-0.30	2.25
Massflow. $\dot{m}$	$\frac{kg}{s}$	Set as pressure outlet BC	0.16	Set as pressure outlet BC	0.10	0.16
Turbulent kinetic energy (TKE) k	$\frac{J}{kg}$	Zero gradient BC	7.56e-2	Zero gradient BC	Zero gradient BC	7.56e-2
Rate of dissipation of TKE. ϵ	$\frac{m^2}{s^3}$	Zero gradient BC	1.21	Zero gradient BC	Zero gradient BC	1.21

The calculations are performed with 1.93 million cells in A-H0602 and 1.69 million cells for E-H0702. Both simulations are run up-to 5,000 iterations and the steady-state solutions are considered with the residuals dropping below 10^{-4}.

Figure 6: A-H0602 Fan coil

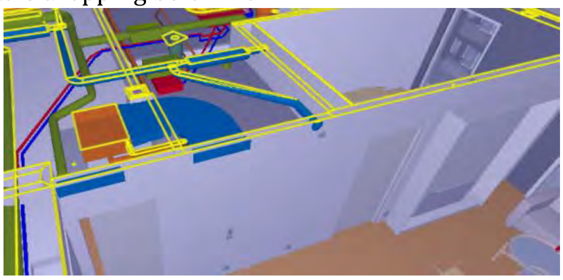

Figure 7: A-H0602 in Solibri 3D model.

Figure 8: E-H0702 Fan coil

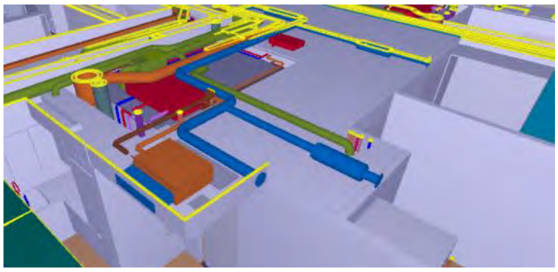

Figure 9: E-H0702 in Solibri 3D model.

Energy needs and consumption

The energy requirement for space heating and tap water is calculated using dynamic building simulation tool SIMIEN (IBPSA-Nordic). The different zones depend on technical installations, usage patterns and simulation purpose. Each apartment is divided into three different zones for differentiation of heating type (see Figure 10,11). Heated zones can in principle be merged, but due to different heat emissions, the living room / kitchen and bathroom are kept as separate zones. Due to the negligible heat emission in the bedrooms, these are considered as a separate zone as well.

Figure 10: Zones for E-H0702

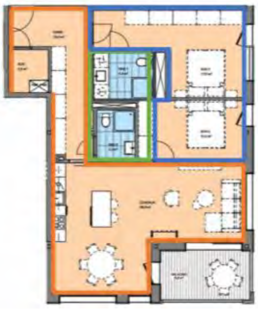

Figure 11: Zones for A-H0602

Figure 12 shows an overview of energy supply for the heat demand in the apartments of Dronninglunden. The heating coil in the air handling unit (AHU) is powered by electricity, while the combined distribution network for space heating and domestic hot water is hydronic supplied with district heating.

Figure 12 Energy flexibility of total heat requirement. Green is hydronic heating, blue direct electric.

The proportion of energy coverage from source in relation to the total energy requirement is calculated (see Equations 1 & 2) where units and sizes are corresponding to those defined in NS 3031:2014 (SIMIEN, 2015). Equation 1 is for Percentage flexible energy consumption in Dronninglunden and Equation 2 is for Percentage non-flexible energy consumption in Dronninglunden.

$$dQ_{Flexible} = \frac{Q_{main\ heating}}{Q_{tot}} + \frac{Q_{DHW}}{Q_{tot}} \quad [\%]$$

$$dQ_{Electric} = \frac{Q_{vent.heating}}{Q_{tot}} \quad [\%]$$

Hygienic security

To determine the quality of the system's protection against the legionella bacterium, the design and use of the heating system are examined quantitatively and qualitatively. A quantitative survey is first carried out through an inspection of the facility on 05/05/2020 as well as inspection of drawings, this data was compared with guidelines and regulation.

After the inspection, a qualitative study is performed with consultation of leading experts in hydronic heat and water treatment. The following people are contacted via e-mail and telephone interview:

- Engineer B.Sc Per Eivind Larsen
- Dr. Scient. Biology Hanne Therese Skiri
- Professor PhD Natasa Nord
- Engineer M.Sc David Zijdemans

RESULTS AND DISCUSSION

The distribution system

The manifold cabinets for the direct 3-pipe system from LK Systems are delivered with the prefabricated bathroom cabins, where one bathroom cabin per living unit is specially adapted with this special cabinet. AF Gruppen was able to document that the extra material and installation costs for the special adaptations amounted to 2,437,000 NOK ex. VAT. Divided into 138 apartments, this is an additional cost of 17,659 NOK per apartment, compared with a traditional bathroom cabinet (AF Gruppen, 2020).

At Dronninglunden, a total of 140 fan coils are installed for space heating purposes. AF Gruppen's cost documentation indicates a fixed price for material and installation of each fan-coil where the cost per unit is 7,500 NOK ex. VAT. The installation itself had a fixed price of 1,500 NOK ex. VAT, which gives a total of 1,260,000 NOK ex. MVA (AF Gruppen, 2020).

With hydronic heat in the apartments, it will require additional piping compared to direct electric space heating. In addition to standard piping with cold and hot tap water, piping for the fan coil and secondary bath (see Figure 13) is needed. Cooling is an option for buyers and is not included in the calculation.

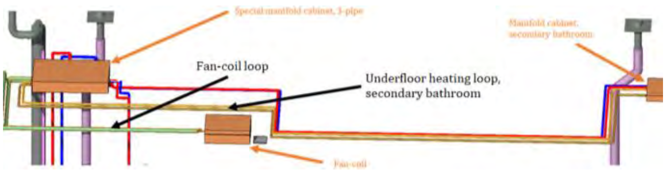

Figure 13 Setup of pipes in the apartments at Dronninglunden in a screenshot from Revit. Piping designated in black would not have been installed in an direct electrical system solution.

The costs for the heating system's piping are not documented by AF Gruppen, but the Revit model for HVAC was made available for further investigation. With the BIM model, pipe lengths are calculated, and costs estimated with "Norsk Prisbok 2019" (Norsk

Prisbok 2019). The resulting calculation are shown in Table 3, where the total cost of the extra piping is estimated at 131,217 NOK ex. VAT, or 950 NOK ex. VAT per dwelling unit on average.

Table 3: Pipe lengths in connection with fan coil and underfloor heating calculated on Excel and Revit. Costs are taken from the Norsk Prisbok 2019 (Norsk Prisbok 2019).

Type	Diameter [mm]	Length [m]	Material [kr/m]	Installation [kr/m]	Kostnad [kr]
PEX	**16**	**1 697**	163	110	**55 885**
-Iso	*20*	1 180	-	-	-
-Iso	*8*	*517*	-	-	-
PEX	**20**	**204**	221	147	**75 332**
-Iso	*20*	*204*	-	-	-
Total		**1 902**			**13 1217**

AF Gruppen estimated in their Enova application that costs for equivalent electrical equipment and installation wiring and panel heaters is 22,000 NOK ex. VAT per apartment, or 3,036,000 ex. VAT for the entire building. This calculation does not consider the possible need for increased transformer size as well as electrical installations outside the apartment. With these findings, the additional cost for a direct 3-pipe system with a fan coil can be roughly compared with what is considered a cost-effective direct electric heating system, and shown in Table 4, the additional cost is estimated at 67 NOK per m² ex. VAT.

Table 4: Cost estimate of three-pipe system with fan coil compared to direct electric heating.

		Pipes	Fan-coils	Distribution cabinets	Panel heaters	Cost
Total cost	10^3Kr	131.2	1 260	2 437	-3 036	**792.2**
Cost per m²	Kr/m²	11.1	106.7	206.4	-257.2	**67.1**

This additional cost can be compared with the property price per square meter for the apartments at Dronninglunden, which as of May 2020 had an average price of 111 749 NOK per m2. The extra cost of hydronic heat will only be 0.06 percent of the price per square meter. (Røisland&Co, 2020)

Unlike the traditional hydronic solutions, the 3-pipe system has a de-centralized heat circuit in each apartment, which means several components usually found in the plant room, is placed in each apartment and is the owner's responsibility to maintain. The components have an estimated service life of 15 years and with decentralization of the components, the end user is financially responsible for the acquisition of new components as well as service. These components have a total value of 5,727 NOK excluding installation costs. Hourly price per FL-VA / VVS, which is considered the industry's common sales and delivery terms, was as of January 2020 at 728 NOK ex. MVA (FL/VA-VVS, 2020). The estimated installation time per component is 2 hours. Table 5 shows an overview of the components' cost, as well as the total cost for replacement and installation of all components. With a lifespan of 15 years, these result in a hypothetical annual cost of upkeep at 746 NOK including VAT.

Table 5: Estimated cost of upkeep. (Trandem & Dalen, 2019) (FL/VA-VVS, 2020)

	Cost estimate (NOK)
Circulation pump	1 595
Expansion vessel	1 375
Plate heat exchanger	2 757
Installation incl. VAT	5 460
Total	**11 187**

Hydronic heating also comes with some financial benefit, as price for district heating is considered cheaper than electricity. Using average prices as of 2019, the annual savings becomes NOK 2,853 per apartment, as shown in Table 6.

Table 6: Calculation for annual savings for district heating, versus electricity. Calculated average energy use 5 521 kWh for space heating per apartment.

	Cent/kWh (NOK)	Monthly expense (NOK)
District heating energy	63.23	3491
Electric energy	114.9	6344
Difference		2853

With an estimated saving of 2,853 NOK per year for district heating, the decentralization of components is not considered an economic challenge for the end user. The annual savings for the end user is 2,107 NOK with service on components considered.

Heat emitter and indoor climate

Field measurements

Air velocities

High air velocities can cause cooling effect, dry mucous membranes and discomfort for the occupants. Ideally air speed should not exceed 0.2 m/s within the residence zone (within 1.8 m of floor, and 0.6 m from walls) The authors intended to investigate if such velocities could be produced by the fan coil. During field measurements in apartment H0602, no such velocities is detected. In contrast, apartment E-H0702 is found to have several points in which velocities exceeded acceptable limits. The authors hypothesised that the intended coandă effect is being disrupted by a submerged beam of 18 cm, and redirected airflow down from the roof onto the occupants. CFD simulations are performed to analyse the airflow to substantiate the hypothesis and the measurements. Results of field measurements and simulation are stipulated, compared, and presented in the following section.

Air temperatures and operative temperatures

Due to lack of heat demand during days of measurements, no specific conclusions could be drawn between indoor temperature and fan-coil heating efficiency. Measurements of temperature were still made to rule out any significant faults in thermal comfort. Unpleasant vertical temperature differences were not found, as the largest vertical temperature difference is found to be 0.9 ºC with a median of 0.1 ºC. The operative temperature is found to be higher than desired, with over 26 ºC in both apartments at one point. These high temperatures are hypothesized to be due to direct sunlight exposure of the interior before measurement. Although it is noteworthy that automated sun protection should be considered to lower the cooling demand and improve indoor environmental quality.

Thermography

As an auxiliary tool for visualizing a possible disruption of airflow by the construction beam in apartment H0702, the roof is exposed to IR-imaging. We found clear indications that the beam is hindering airflow in the resulting images in Figure 14.

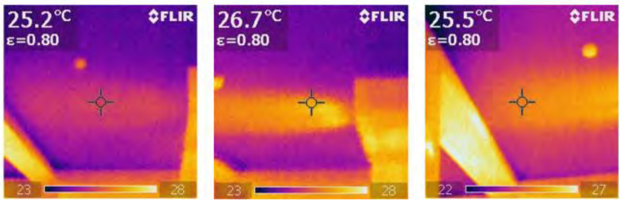

Figure 14 Visualization of a sabotaged coandă effect using differences in radiant temperatures.

Airflow simulation with STAR CCM +

Figure 17 illustrates how the air flow from the fan-coil moves in the simulation, where colour-scale illustrates air velocities. The results from CFD calculations show high velocities immediately from the exhaust, and a decrease in speed along the roof. It is observed that air flow in E-H0702 is disrupted by the 18 cm submerged beam which changes airflow direction directly into the occupied zone. Figure 15 and Figure 16, show the comparison between simulations and the values from the field measurements. Correlation are observed between measured and simulated values, although with some discrepancies.

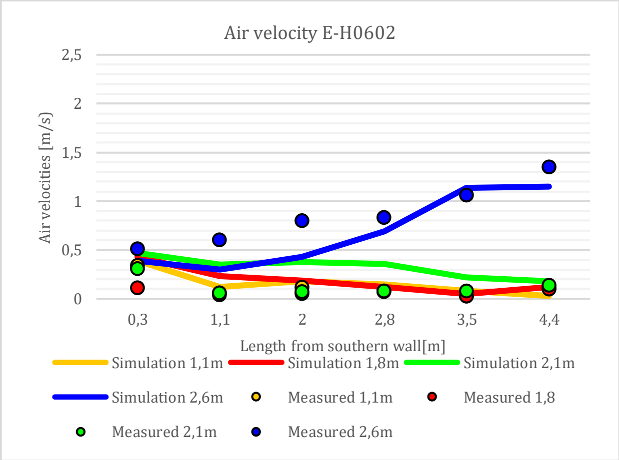

Figure 15 Graph of simulation and measurements taken at the same points in A-H0602. Flow direction towards the left side.

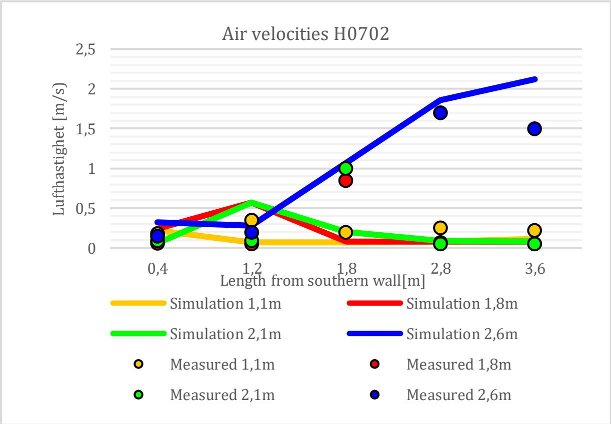

Figure 16: Graph of simulation and measurements taken at the same points in E-H0702. PS: No data at x=1.8 and 2.6m height due to the presence of the beam. Flow direction towards the left side.

The simulations confirm the initial hypothesis that the beam provokes a disruption of the airflow, which causes sufficient drafts leading to feeling of discomfort. In the case of H0602, the airflow from the fan coil moves undisturbed and is kept satisfactory within the occupant zone.

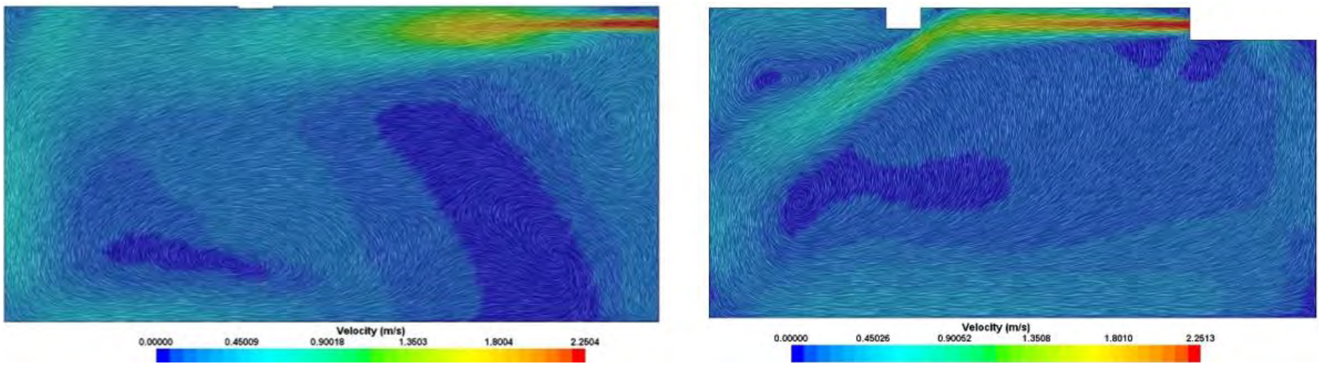

Figure 17 Vector scene with air velocities in the two apartments. The scale goes from 0.00 to 2.25 m / s

Energy needs and consumption

Table 7 shows the energy requirements for a full year simulation by SIMIEN.

Table 7: Energy for space heating

Apartment	Heating	Required energy kWh	Specific energy required $\frac{kWh}{m^2}$
A-H0602	Room	3867	41,1
	Air supply	448	4,8
E-H0702	Room	3592	45,9
	Air supply	470	6

This gives us a total energy requirement for heating of A-H0602 and E-H0702 of 4315 kWh and 4062 kWh, respectively. The values for DHW (presented in Table 8) are extracted from the simulations. The direct 3-pipe solution must be able to supply the energy for both tap water and space heating.

Table 8: Energy for DHW

Apartment	Required energy kWh	Specific energy required $\frac{kWh}{m^2}$
A-H0602	2800	29.8
E-H0702	2329	29.8

Figure 18 and Figure 19 show the coverage of standardized net heat demand. Tap water and space heating that are covered with an energy-flexible heating system (hydronic) are marked in orange, and direct electricity is marked in blue. It can thus be seen that the simulated coverage rate for hydronic heat for apartments A-H0602 and E-H0702 is 94 and 93 percent, respectively. The remaining 6 and 7 percent of the heat demand is covered by heating of supply air (direct electricity).

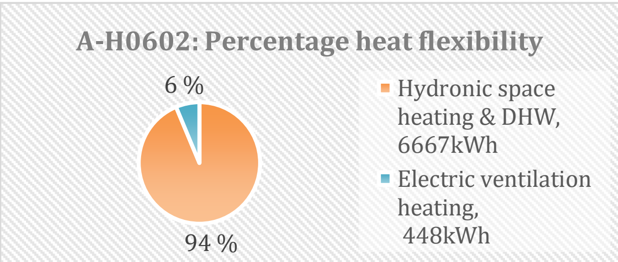

Figure 18: Energy flexibility of E-H0602

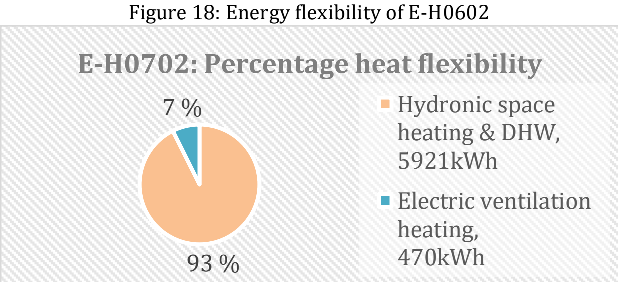

Figure 19: Energy flexibility of E-H0702

Thus, one can conclude that the apartments satisfy the requirement as over 60 percent energy flexible.

Hygienic security

The principle design of the direct 3-pipe system deviates from the regulatory advice in TEK 17 where a minimum of 65 ° C is required in the DHW circulation loop. It is still possible to comply with the regulations by referring to other measures that prevent the occurrence of legionella, of which Norconsult and Kompa separately has documented what measures would be satisfactory in the case of 3-pipe systems (Monan, 2015) (Skiri, 2020). When implementing these measures, a deviation from regulation could be justified when measures hinder bacterial growth. 3-pipe systems can therefore be utilized to achieve hygienic security while satisfying the regulations

The implementation of said measures is assessed in two parts.

- First, the heating system is inspected and compared with the recommendations from the reports of Norconsult and Kompa.
- Secondly, the discrepancies are assessed by the authors with the assistance of experts in hydronic systems and legionella, thereof writers of the Kompa report.

The heating system at Dronninglunden is found to have no measures in place preventing bacterial growth beyond what exists in traditional hydronic systems, it could not be documented that the plant's design justifies the deviation from building code. It could thus be concluded that the hydronic system has deficiencies that violate TEK17. With feedback from experts, three possible alternatives are proposed to solve the lack of satisfactory hygienic security.

1. *Install a microbiological barrier in the plant room*

   Installation and maintenance of an Advanced oxidation process (AOP) reactor will provide significant investment and maintenance costs but can provide protection against legionella entering the system through the cold water inlet.

2. *Raise the DHW temperature by ~ 5–10 ° C*

   At high temperatures, most Legionella bacterium could be eliminated before reaching the first DHW-outlet. In order to determine the correct temperature increase, new calculations should be made. The increased temperature would not require adjustment in the apartments as the tap water temperature is individually thermostatically controlled. The disadvantage of higher temperature is a greater heat loss in the distribution network, which in turn could result in increased operating costs.

3. *Install digestion boiler*

   With a digestion boiler, water travel time between the heat exchanger and the first outlet would reportedly increase enough to ensure elimination of Legionella bacterium. The investment cost of the boiler is assumed to be significantly lower than the microbiological barrier and would have low operating cost. Moderate increase in flow temperature will significantly lower the required boiler volume, but higher flow temperature will also result in increased heat loss. A more thorough calculation should be made to assess whether a smaller boiler volume with a higher temperature is cost-effective in the long term.

In general, a control function is recommended in the Industrial control system (ICS) that would warn operators in the event of deviations in temperature, when using a digestion boiler, the measuring point should be set after the boiler. It should also be considered whether the existing expansion vessel should be switched to one with constant flow to eliminate dead ends where legionella could fester.

CONCLUSIONS

The findings show that it is possible to build modern apartment blocks with very high energy flexibility and a low additional cost. It is estimated that the building Dronninglunden has achieved over 90 percent energy flexibility with only 67 NOK per square meter additional cost compared to direct electric heating. This demonstrates that buildings with more than 1,000 m^2 can have energy-flexible heating that covers more than 80% of the heating demand without significantly affecting the developer and contractor in terms of costs. The end user will in turn have reduced energy costs without notable impact on housing cost. This method of designing hydronic heating systems can therefore be expected to become far more widespread in the near future, but the industry has little experience in how it could be designed and optimized. The following experience should therefore be considered in future use:

- the use of fan-coils must be accounted for early in the planning phase to avoid placement of construction elements that hinder proper airflow.
- specific measures must be planned against bacterial growth to prevent violations of TEK17 §15-5. Direct 3-pipe system design does not violate TEK17 in and of itself with the correct design, but at Dronninglunden a reassessment should be made.

Finally, it is important that we as society rethinks and challenges old methods. This study has shown that it does not necessarily need to be expensive to build energy- and climate-friendly system solutions that also are economically advantageous.

ACKNOWLEDGMENTS

We would like to thank our supervisor from AF Gruppen, Tor Olsen, for his knowledge of the Dronninglunden project as well as his professional input. Furthermore, we would like to thank the experts in hydronic systems and water treatment; David Zijdemans, Hanne Therese Skiri, Natasa Nord and Per Eivind Larsen for professional input and sharing of experiences about direct 3-pipe solution and legionella in hydronic heating systems. We would also like to thank Ole Melhus for his professional guidance and advice. Thanks are due to Ernst Erik Hempel for assistance with SIMIEN calculations and lending of instruments during a period where OsloMet was closed due to Covid-19. Finally, we would like to thank Terje Kristoffersen at Oslo S Utvikling for accessing and lending keys to the apartments mentioned in the thesis.

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