

## **Energy use in Norwegian non-residential buildings: building regulations, calculations and measurements**

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### **SUMMARY**

The objective of the study is to give an overview on the energy use in Norwegian non-residential buildings in order to achieve better energy planning. The questions addressed are the division of energy use according to the purpose and the correspondence between measured and calculated energy use. The building categories discussed in more detail are office buildings, commercial buildings, hospitals and educational buildings. When comparing measured and calculated energy use, big deviations have been reported in all the discussed building categories such that the calculated energy is clearly lower than the measured use for new buildings, and vice versa for old buildings. The difference between the calculated and measured energy use varies from 5% for schools to 95% for supermarkets. The reasons for the discrepancy are discussed for each building category. It was estimated that an error of one third in the installed heat rate could be made when designing an energy supply plant for a development owing to the discrepancy.

### **INTRODUCTION**

Buildings account for more than 40% of the global energy use, and as much as one third of the global greenhouse gas (GHG) emissions, both in the developed and the developing countries (UNEP SBCI 2009). In Norway, buildings' energy consumption was 80 TWh in 2011, corresponding to 40% of the total energy use. If energy efficiency in the building sector is not improved, the current energy demand in the buildings sector is expected to rise by 50% by 2050 (International Energy Agency (IEA) 2013).

The energy demand is particularly high in many industrial and non-residential buildings, however it is generally difficult to obtain detailed data from the energy consumption by this sector (Pérez-Lombard, Ortiz et al. 2008). At the same time these buildings often have processes or equipment with high production of excess heat; such as computer facilities at universities, refrigeration systems at supermarkets, or technical equipment at hospitals. In this study, the energy use in Norwegian non-residential buildings is reviewed, with respect to the general energy use patterns as well as the correspondence between measured and calculated energy use. The objective is to get an overview on the real energy use in non-residential buildings in order to better plan the energy supply systems. The building categories discussed in detail are office buildings, commercial buildings, hospitals and educational buildings.

## METHODS

The data for energy use in non-residential buildings was gathered from national databases and in some cases from reports employing actual measurement data from individual buildings. The data in national databases is generally based on energy bills of building owners, gathered through questionnaires (Statistics Norway 2013). For each building category, first the national statistics and requirements are presented, followed by the actual energy use based on measurements from individual or several buildings.

## RESULTS

Figure 1 presents the specific energy use for different non-residential buildings in Norway in 2011 according to the building year. The overall average annual specific energy use was 230 kWh/m<sup>2</sup>; however the energy use varies a lot among the different building categories, correlating strongly with the operation time, as is shown in Figure 2. Further parameters affecting the energy use are location, amount and type of technical equipment and appliances, and the focus on energy efficiency. The category with clearly highest specific energy use is hospital buildings, with on average 366 kWh/m<sup>2</sup>·year, followed by nursing homes, sports buildings and hotels. The high energy demand in hospitals and nursing homes can be explained with the high operation time, high demand for ventilation air and high amount of technical equipment. On the contrary, school buildings (including primary and high schools and kindergartens) have a low specific energy demand owing to the relatively low operation time and low amount of technical equipment. Buildings for religious activities have usually low operation time, but often a high ceiling, which increases the heating costs. For sports buildings, there is a significant peak in facilities built in the period 1950-69, probably due to the high number of swimming facilities built in this period (Kampel, Aas et al. 2013).

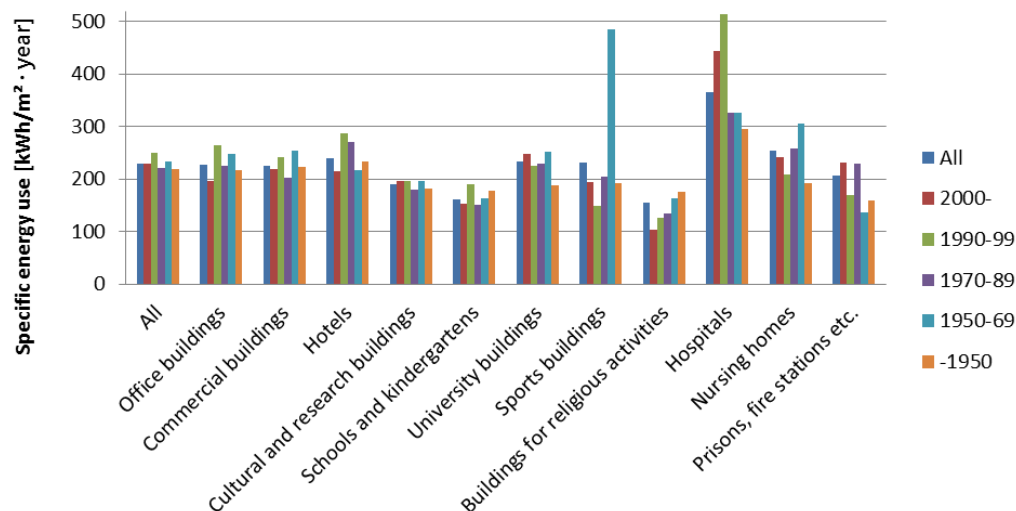


Figure 1. Average annual specific energy use according to the building category and building year in Norway in 2011 (Statistics Norway 2013).

Interesting to note from Figure 1 is that the specific energy use is not necessary lower for newer buildings as compared to older. Even though the building regulations have become stricter, the amount of technical equipment as well as the operation time has increased in many building types, and the requirements for indoor air quality have become higher, leading to higher energy consumption. This will be discussed in more detail in the following sections.

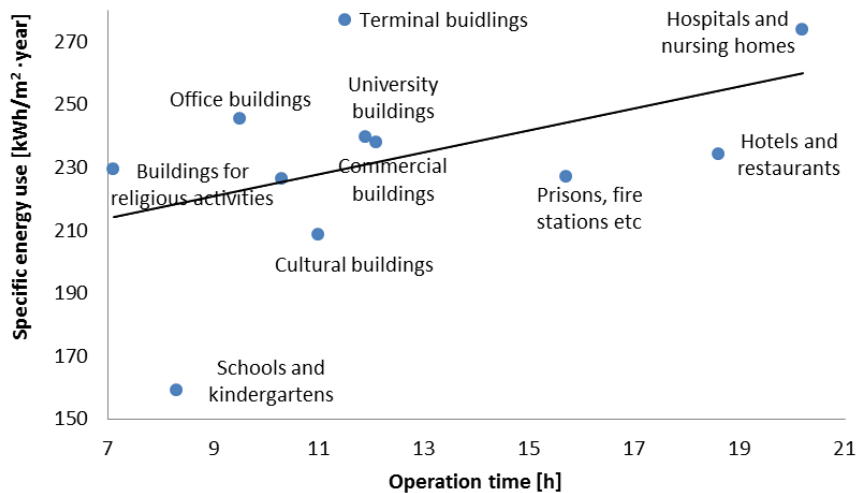


Figure 2. Specific energy use as a function of the operation time for Norwegian non-residential buildings (Abrahamsen and Bergh 2011).

### Office buildings

Office buildings are fairly energy intensive buildings, with an average specific energy use of approximately 230 kWh/m<sup>2</sup>·year. According to the current national building regulations (TEK10), the limit is 136 kWh/m<sup>2</sup>·year for a normalized (Oslo) climate (Enova 2012). In office buildings, energy is used primarily for room heating (through ventilation and radiators), technical equipment, lighting, and cooling. Figure 3 (a) shows the calculated energy use according to the purpose, based on the national building regulations (TEK) for different years. According to the calculations the energy demand for room heating and ventilation heating has reduced significantly, from 97 kWh/m<sup>2</sup> based on TEK87 to 40 kWh/m<sup>2</sup> based on TEK10 (Fiksen, Grøndahl et al. 2012). At the same time the share of energy used for technical equipment has increased from 14 to 27% when comparing TEK87 and TEK10, although the total energy use for this purpose has remained the same.

The actual energy use has nevertheless not decreased until the very recent years. The actual use is generally higher than calculated use for new buildings and lower for old buildings (Figure 3 (b)). The calculations for heating, domestic hot water (DHW) and lighting are often in accordance with the actual use for office buildings; however the energy use for ventilation, fans, pumps and cooling is generally higher for new buildings than assumed in the calculations (Fiksen, Grøndahl et al. 2012). Higher energy use for ventilation and cooling might be due to different occupant pattern and operation than expected in the calculations, and due to higher requirements for indoor air quality. The actual operation time (see Figure 2) might also be higher, increasing the energy required for heating, ventilation and lighting.

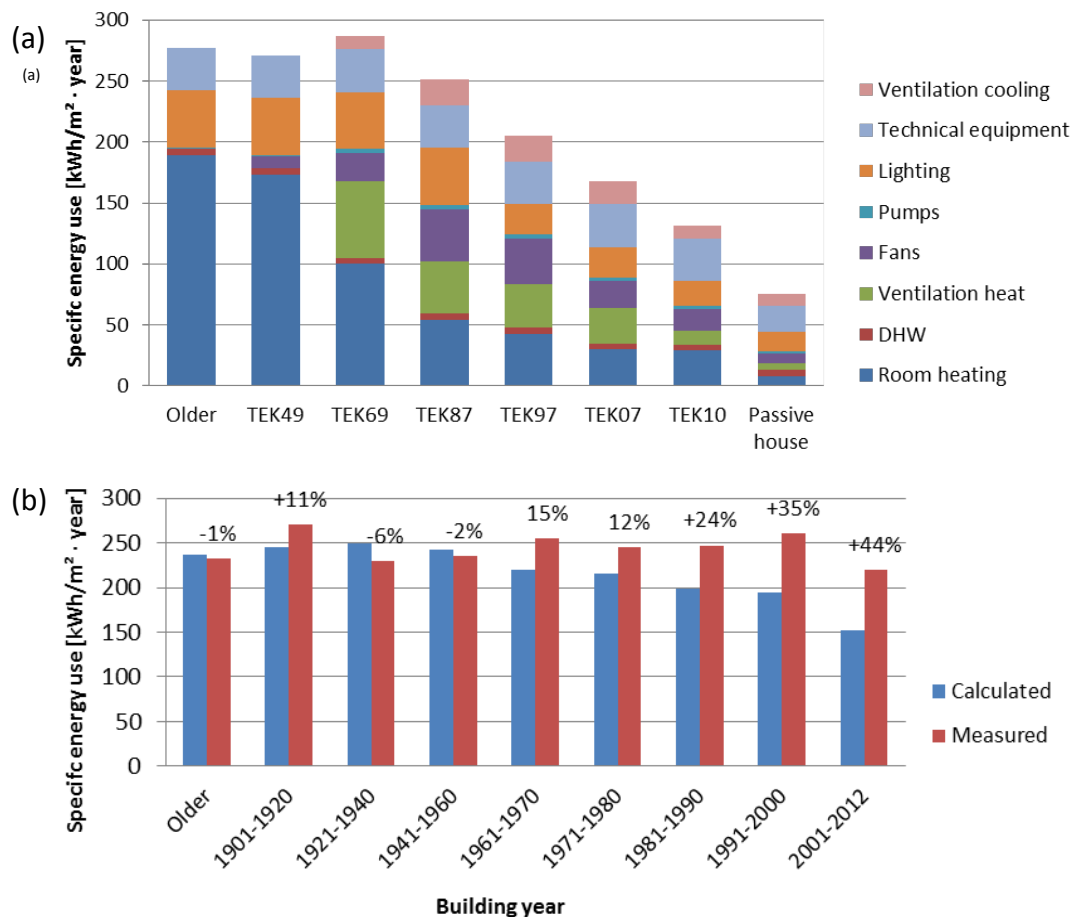


Figure 3. (a) Calculated specific energy use in Norwegian office buildings according to the purpose based on Norwegian building regulations (TEK) and (b) calculated delivered energy based on building regulations (blue) vs the measured energy use (red) according to the building year (Fiksen, Grøndahl et al. 2012).

### Commercial buildings

Commercial buildings include grocery stores, shopping centres and other individual stores, and gas stations. The total energy use in commercial buildings in Norway is almost 11 TWh/year, which corresponds to 30% of the energy use in non-residential buildings. The limit for specific energy use according to the building current regulations (TEK10) is 210 kWh/m<sup>2</sup>·year for a normalized climate (Enova 2012), and the actual energy use was 226 kWh/m<sup>2</sup>·year in 2011 according to the national statistics (Statistics Norway 2013). The energy use of the different buildings in this category however varies depending on the source, owing to for instance varying grouping of the buildings, and varying definition of the store area (NVE 2014a). The energy use of shopping centres is 228-285 kWh/m<sup>2</sup>·year based on different statistics. In most sources grocery stores are not differentiated; according to some sources their energy use is as high as 460 kWh/m<sup>2</sup>·year (NVE 2014a).

Figures 4 (a) and (b) present the actual energy use according to the purpose for shopping centres and grocery stores, respectively. The presented data is based on the measured energy use for at least 5 buildings of each type. For shopping centres, the total energy use was 316 kWh/m<sup>2</sup>·year. The biggest post is electricity to the tenants, including lights and electric equipment; the second largest posts are heating and ventilation. The energy demand for lighting is high due to the display of products.

The total energy use of the grocery stores presented here was 599 kWh/m<sup>2</sup>·year. In grocery stores, most energy is used for the refrigeration systems (central and plug-in), which account for 48% of the total energy use. Thereafter the biggest energy users are lighting, pumps and technical equipment, and ventilation.

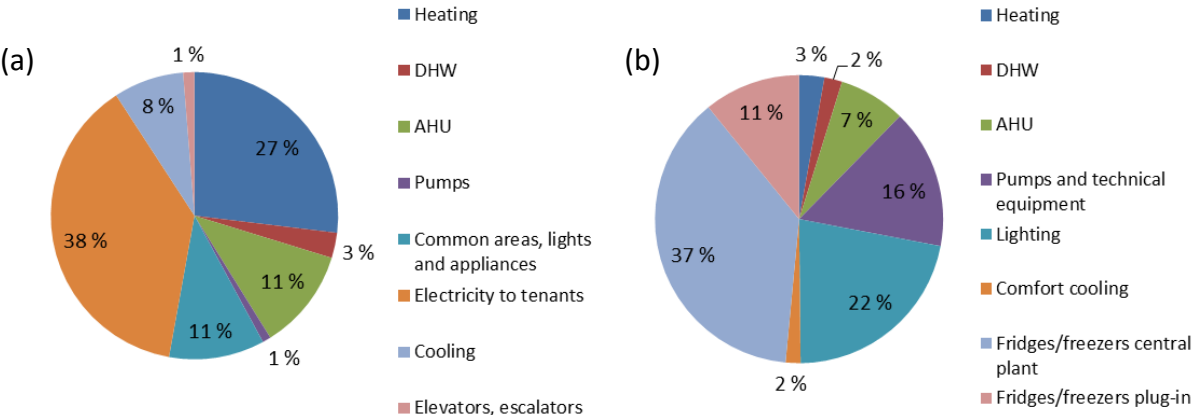


Figure 4. Energy use according to the purpose for (a) shopping centres (representative values for 10 shopping centres with an average total energy use of 316 kWh/m<sup>2</sup>·year) and (b) grocery stores (representative values for 5 stores with an average total energy use of 599 kWh/m<sup>2</sup>·year) (NVE 2014a).

Similarly to office buildings, the calculated energy use for commercial buildings is generally lower than the measured use, especially for newer buildings. For shopping centres built after 2000, the measured energy use was 54% higher than the calculated use, and for groceries the measured use can be even 95% higher (NVE 2014a). The high discrepancy for grocery stores is probably because the standardized values for energy use of the refrigeration systems are underestimated. Another reason for the big difference between calculated and measured energy use might be that the used simulation tools are not suitable for modelling commercial buildings and grocery stores.

**Hospital buildings**

Hospitals are among the most energy intensive buildings, as mentioned earlier. According to the national building regulations (TEK10), the maximum allowed specific energy use for hospitals is 300 kWh/m<sup>2</sup>·year, and 335 kWh/m<sup>2</sup>·year for areas where heat recovery of ventilation air involves a risk of contamination of the supply air (Martinez, Rohde et al. 2011). The actual energy use for Norwegian regional and university hospitals is around 394 kWh/m<sup>2</sup>·year while smaller local hospitals with fewer functions use approximately 18% less (Aasen 2013). Hospitals with laboratory activities have generally high energy demand.

Figure 5 presents the energy use according to the purpose for 2010 for a big Norwegian regional hospital built in 2008, with a total annual specific energy use of 417 kWh/m<sup>2</sup>. Note that the data is not temperature corrected, and 2010 was 8% colder than a normal year. The biggest individual energy post is heating of ventilation air, with 27% of the total energy use. This is more energy demanding in hospitals than in many other buildings as use of regenerative (e.g. rotating) heat exchangers with high efficiency is limited in due to mixing of exhaust and supply air, and hence possible contamination of the supply air. Furthermore, the demand for ventilation is generally high in hospitals, thus heat is primarily distributed by the ventilation air and secondarily by radiators, which correspond to only 12% of the total energy demand. Apart from ventilation and room heating, high temperature heat is required for

various hospital functions, and low temperature heat for snow melting. Cooling demand is also high for this particular hospital, corresponding to 16% of the total energy demand. An inspection of the monthly variation of the cooling demand showed that the demand is mostly due to processes in the hospital rather than comfort cooling (Martinez, Rohde et al. 2011). Approximately one third of the energy demand goes to electrical equipment, primarily lighting and technical (hospital specific) equipment.

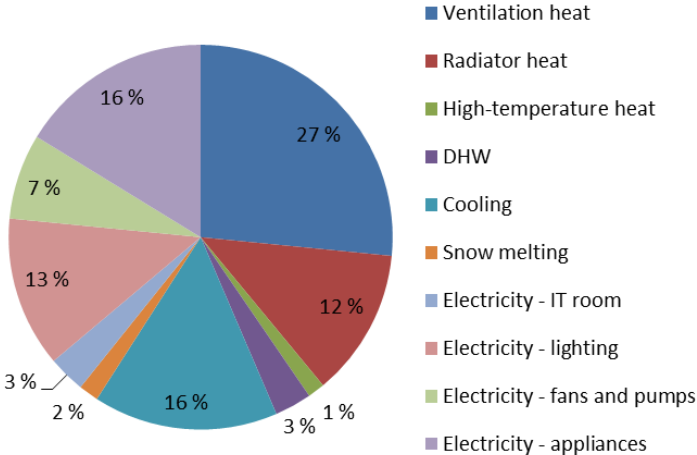


Figure 5. Energy use according to the purpose in 2010 for a big regional hospital built in 2008 with an area of 113 000 m<sup>2</sup> and a total specific energy use of 417 kWh/m<sup>2</sup> (Martinez, Rohde et al. 2011).

**Educational buildings**

Educational buildings, including kindergartens, schools and university buildings are moderate energy users. The energy use limit according to the national building regulations (TEK10) is 131 kWh/m<sup>2</sup>-year for kindergartens, 111 kWh/m<sup>2</sup>-year for schools and 144 kWh/m<sup>2</sup>-year for university buildings for a normalized climate (Enova 2012). The actual energy use is estimated to be 200 kWh/m<sup>2</sup> for kindergartens, 170 kWh/m<sup>2</sup> for schools and 260 kWh/m<sup>2</sup> for university buildings (NVE 2014b). Figure 6 presents the energy use according to the purpose for these three building types. The values presented were chosen as representative values from a detailed analysis of several individual buildings.

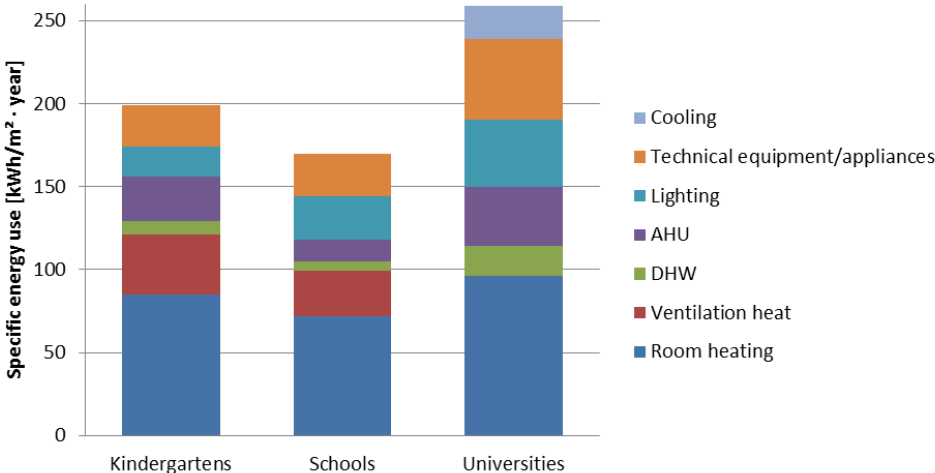


Figure 6. Energy use according to the purpose for educational buildings: kindergartens, schools and universities (NVE 2014b).

The high specific energy use of kindergartens with respect to schools is related to higher indoor temperatures (often as high as 24°C), smaller buildings and longer operation times (NVE 2014b). Heating accounts for 60% of the total energy demand. Relatively high share (13%) is also consumed for household appliances (refrigerators, dishwashers etc). The operation times are long as many kindergartens are open also in the summer holidays. On average, kindergartens are in use 10 hours per day, 5 days per week.

The low specific energy use of schools is primarily due to the low operation times: most schools are in operation 7-8 hours 5 days per week, and many are kept close 12 weeks during a year owing to school holidays (NVE 2014b). The air handling unit (AHU) is off during these periods, leading to a surprisingly low share of energy used for ventilation (8%). The biggest energy post is heating, with 58% of the total energy demand. Similarly to kindergartens, the energy used for lighting is fairly modest, as often energy efficient lights are used.

Universities differ from the first two with longer operation times, and the need for a high number of computers, laboratories and server halls, which consume a lot of energy and also create a demand for cooling. Heating accounts for only 37% of the total energy demand, and technical equipment for 19%. Cooling, which was not present for kindergartens and schools, corresponds to 8% of the demand. The energy use for DHW supply is also clearly higher than in schools and kindergartens, which can be explained with the longer operation hours, as well as the presence of cantinas and cafés in university buildings.

For both kindergartens, schools and universities, the calculated energy use is lower than the actual use for older buildings, and higher than the actual use for newer buildings (NVE 2014b) – similarly with the other building types discussed here. There are several reasons for this. For ventilation rate, normative minimum values are used in calculations for all building years. In older buildings the actual ventilation rate is however probably lower, leading to a lower energy use but also lower indoor air quality. For newer buildings the opposite might be true. For buildings built after 2000, the measured energy use was 20% higher than the calculated use for kindergartens, 5% for schools and 37% for universities (NVE 2014b).

## **DISCUSSION**

In the presented data, significant deviations between the measured energy use and the calculated use, based on the current building regulations, have been observed. A coarse estimation has been made on the possible consequences of this deviation when designing an energy supply plant. It was assumed that a development with a total heated area of 200 000 m<sup>2</sup> will be built, consisting of office buildings, hospitals, commercial buildings, schools and kindergartens. The areas of the individual buildings were estimated on the basis of national statistics on the frequency and total area of these building types. Based on the data on measured and calculated energy use, and the proportion of heat of the total energy use (including room and ventilation heating, DHW, and possible high-temperature heat), an error of 33% could be made in estimating the required heat rate (Table 1). An error of one third in the installed heat rate for an energy supply plant is substantial. This could lead in negative consequences in sizing heat pumps, energy wells or other components in the energy plant, and poorly satisfied thermal comfort in the buildings.

Table 1. Estimation on the heat rate demand in a development consisting of offices, commercial buildings, hospitals, schools and kindergartens.

Building type	Area [m <sup>2</sup> ]	Tot. energy use regulation [kWh]	Tot. energy use measured [kWh]	Heat (%)	Operation time [h/year]	Heat rate [kW]	Heat rate deviation [kW]
Office	76 000	10 336 000	16 720 000	45	5 200	1 447	552
Commercial buildings	56 000	11 760 000	19 040 000	27	7 000	734	281
Hospital	30 000	10 050 000	12 510 000	45	8 000	704	138
School	28 000	3 108 000	4 760 000	62	3 000	984	341
Kindergarten	10 000	1 310 000	1 620 000	65	5 000	211	40
Total	200 000	36 564 000	54 650 000		5 640	4 079	1 353

## CONCLUSIONS

In this paper the energy use in Norwegian non-residential buildings has been reviewed with regards to energy use according to different purposes and correspondence between measured and calculated energy use. When comparing measured and calculated energy uses, big deviations have been reported in all the discussed building categories such that the calculated energy is clearly lower than the measured use for new buildings, and often vice versa for old buildings. The difference between the calculated and measured energy use varies from 5% for schools to 95% for supermarkets. It was estimated that this deviation could lead in an error of one third in the installed heat rate when designing an energy supply plant for a development.

## ACKNOWLEDGEMENTS

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