The Active Utilisation of Thermal Mass of Hollow-Core Slabs

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SUMMARY

The hollow-core slabs can be used actively as a cold and heat storage by conducting supply air through the cores to the space. TERMA project (2004-2006) developed several concepts to integrate thermal mass of hollow-core slabs and air-conditioning systems to meet the requirements of energy efficiency and good indoor conditions. The development was done by using advanced modelling and simulation methods. Thermal behaviour of the hollow-core slab integrated to ventilation was also measured in laboratory. Simulation models were validated against these measurements. The basic strategy for thermal mass utilisation during cooling season is cooling down the slab during unoccupied time by night ventilation to decrease the day time cooling need in the room. By active use of thermal mass of hollow-core slabs the indoor temperature can be reduced at least 2ºC. The active use of thermal mass showed 4..10% savings in heating energy, 46..47% savings in cooling energy and 12..23% savings in fan energy compared to systems traditional systems with passive use of thermal mass.

INTRODUCTION

The thermal mass of the building has a big influence on the energy consumption of the building and indoor temperatures. The present European trend is that the heating and cooling energy consumption is more and more emphasised as a basis for the standards and design work .

Passive use of the building mass has been studied widely. The passive use of thermal mass showed energy savings potential of 4..7% in heating energy and 42..52% in cooling energy /1/. Total energy saving potential can be increased by active utilisation of the building mass. Recently in active utilisation it has been focused on the night ventilation and air circulation trough hollow cores in hollow core slabs. According to Hietamäki et al. /2/ in general night cooling decreases cooling power 40% and cooling energy 20%. With active night ventilation trough hollow core slabs has been decreased 15% cooling energy need.

The hollow-core slabs can be used actively as a cold and heat storage by conducting supply air through the cores to the space. TERMA project (2004-2006) developed several concepts to integrate thermal mass of hollow-core slabs and air-conditioning systems to meet the requirements of energy efficiency and good indoor conditions. The main basis was in Finnish office building. The objective was to achieve 10 % reduction in heating and at least 20% reduction in cooling energy consumption compared to recent calculated level of passive effect of thermal mass.

The development was done by using advanced modelling and simulation methods: spatial level dynamic energy simulations for a whole building, detailed 3D thermal modelling of the hollow-core slab and computational fluid dynamic simulations for indoor conditions. Thermal behaviour of the hollow-core slab integrated to ventilation was also measured in laboratory. Simulation models were validated against these measurements. In the end the LCC survey and design guide were done for developed concepts.

The main objectives of this paper are to present modelling and simulation methods and measurements which have been used to find out the potential concepts. The most potential concepts are presented as well as theirs' influences to the indoor comfort and energy consumption.

METHODS

In the beginning of the TERMA project state-of-the-art study of existing systems was done /3,4/. The project continued with study of possible integrated concepts /5/. According to the preliminary studies the development was focused on the integrated hollow-core slabs and air-conditioning system. Figure 1 shows the development of the TERMA concept.

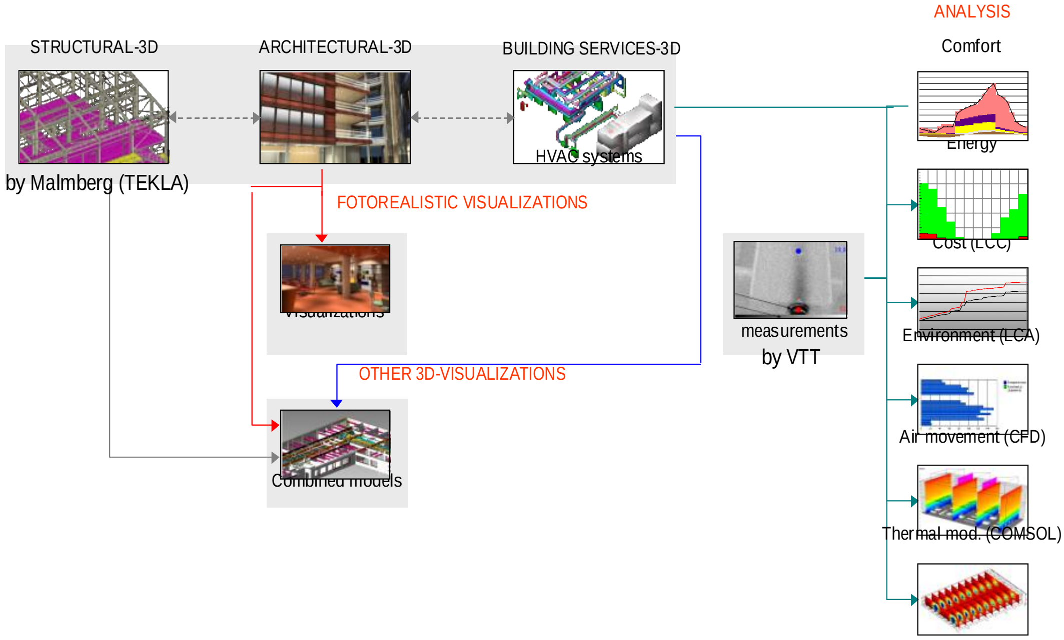


Figure 1. The development of TERMA concepts of utilising advanced modelling, analysis and measurements in TERMA project.

The analysis of the integrated hollow-core slabs and air-conditioning system concepts were done with multiphysic program /6 /. The purpose of the calculations was to determine dynamically in one day period the effect of the air circulated in hollow-core slab to the indoor temperature in south and north faced office rooms in summer conditions. The changing variables were the routing of the air in the slab cores, the temperature of the air conducted to the cores and the supply air temperature from the cores to the room.

The simulations results were indoor temperature, supply air temperature to the room space after core, the temperature distribution of the hollow-core slab and heating and cooling effect of the hollow-core slab to the room space. Figure 2a presents simulated hollow-core slab and 2b the connection between room model and hollow-core slab.

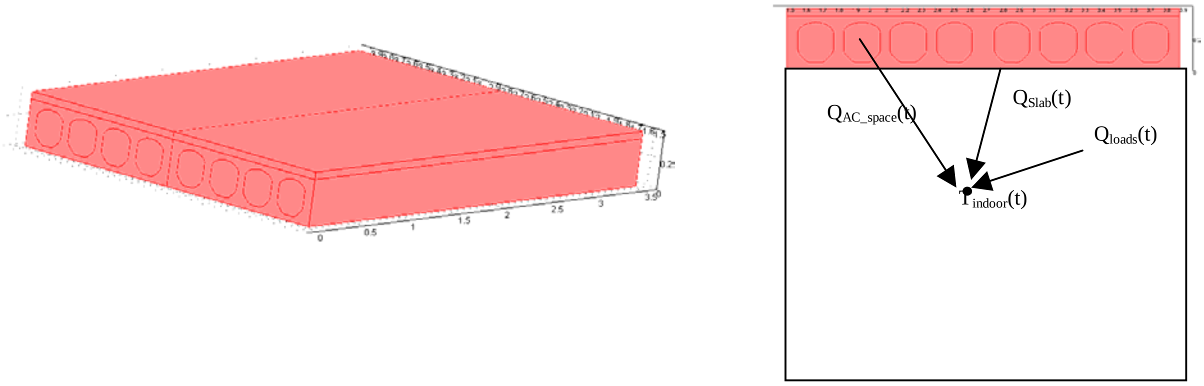


Figure 2. a) Simulated hollow-core slab. b) Connections between hollow-core slab and room model in the multiphysics model.

The energy consumption and heating and cooling needs for office building with different integrated concepts were defined with dynamic energy calculation program /7/ and multiphysics simulation program (Figure 3) /8/.

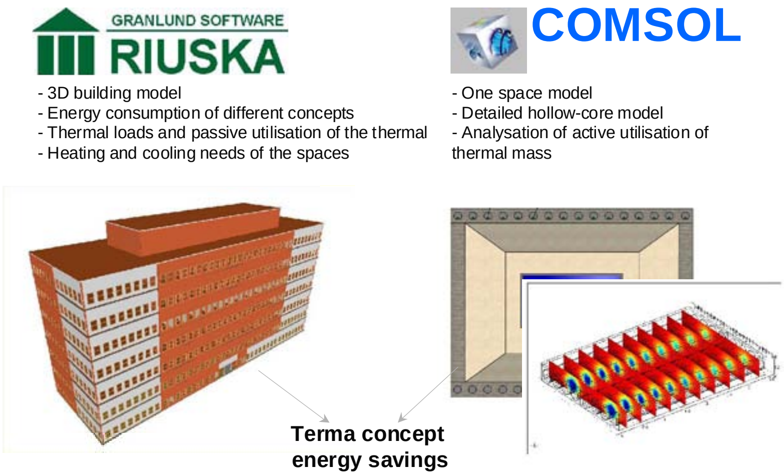


Figure 3. Calculation of the energy consumption and heating and cooling needs.

The energy consumption of the different concepts were compared to typical variable volume air conditioning system (VAV system) and cooled beam system (CB system).

The laboratory tests of the hollow-core slab were performed. The objectives of the tests were to measure and estimate the thermal behaviour of hollow-core slab. One hollow of the hollow-core slab was used as supply air duct of the ventilation system. The inlet supply air temperature was varied like outdoor air temperature in hot summer day (24 h sinus wave model, Tmin=12°C, Tmax=25°C) /9/. The ambient temperature was 20°C. The size of the hollow-core slab was 1200 mm(width) x 400 mm(height) x 10000 mm (length). The measurements were done with two nominal air flows 20 dm³/s and 40 dm³/s in one core. Figure 3a presents the location of the measurement points and figure 3b measurements at 8 m distance.

Measurements of the Terma-slab at VTT Research Hall, Espoo — **Line, x** (distance in meters from the beginning of the slab)

Code	No	Declaration	0	0.5	1	2	3	4	5	6	7	8	9	10	Total
TIx	001	**Air flow temperature inside the main mid-hollow**	1	1	1	1	1	1	1	1	1	1	1	1	12
TIx	002	Air temperature inside the empty right edge-hollow			1				1						2
TIx	003	Air temperature inside the empty mid-hollow			1				1						2
TIx	004	Air temperature inside the empty left edge-hollow			1				1						2
TIx	005	Ambient air temperature above the slab			1				1						2
TIx	006	Ambient air temperature under the slab			1				1						2
TPx	007	**Upper surface temperature inside the main hollow**		1	1		1		1			1			5
TPx	008	**Right surface temperature inside the main hollow**			1		1		1			1			4
TPx	009	**Lower surface temperature inside the main hollow**		1	1		1		1			1			5
TPx	010	**Left surface temperature inside the main hollow**			1		1		1			1			4
TPx	011	Upper surface temperature of the slab, right neck			1		1		1			1			4
TPx	012	Upper surface temperature of the slab, hollow			1		1		1			1			4
TPx	013	Upper surface temperature of the slab left neck			1				1						2
TPx	014	Upper surface temperature of the slab, left (empty) neck			1				1						2
TPx	015	Left edge surface temperature of the slab (insulation)			1				1						2
TPx	016	Lower surface temperature of the slab, left (empty) neck			1				1						2
TPx	017	Lower surface temperature of the slab left neck			1				1						2
TPx	018	Lower surface temperature of the slab, hollow			1				1						2
TPx	019	Lower surface temperature of the slab, right neck			1				1						2
TPx	020	Right edge surface temperature of the slab (insulation)			1				1						2
TPx	021	Floor surface temperature under the slab			1				1						2
TBx	022	Concrete mass temperature above the slab (left neck)			1		1		1			1			4
TBx	023	Concrete mass temperature under the slab (left neck)			1		1		1			1			4
															74
		Total number of measuring points	1	3	23	1	9	1	23	1	1	9	1	1	**74**

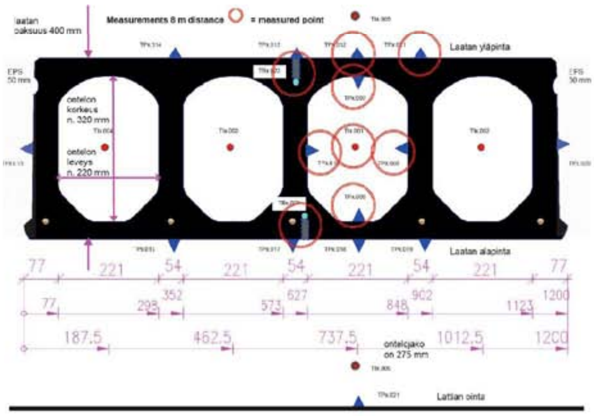


Figure 4.a) The location of the measurement points. b)The measurement at 8 m distance.

The multiphysics model was validated against the laboratory tests.

CFD simulations were performed to ensure indoor comfort in different integrated concepts /10/. The aim of the CFD simulations were to estimate office indoor air flow field on summer design day conditions in case the hollow-core slab were used.

RESULTS

The multiphysic model was validated against laboratory tests. Figure 5 shows as an example the temperature comparison of the supply air conducted trough the hollow-core slab in simulations and tests.

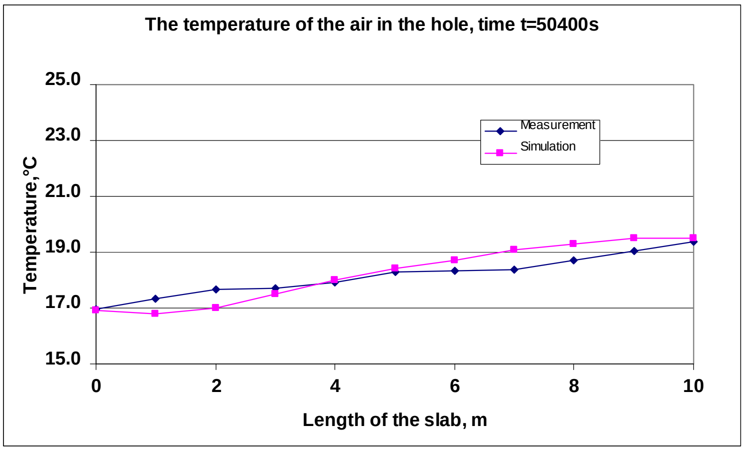


Figure 5. Simulated and measured supply air temperature.

After the multiphysics model was validated, the analysis of the integrated hollow-core slabs and air-conditioning system concepts were performed for 24 different concepts /6/. Figure 6 shows an example of temperature distribution of the hollow-core slab in case where supply air was conducted trough two holes to the space.

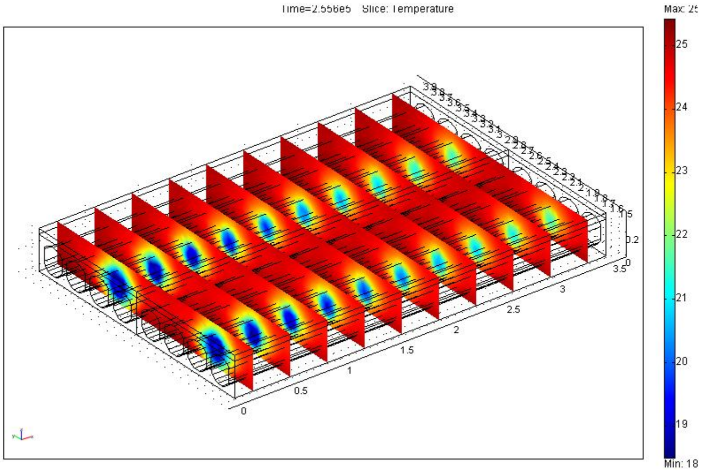


Figure 6. The temperature of the hollow-core structure at midnight.

The results showed that the best indicator for the efficiency of the hollow-core slab as a heat storage is indoor temperature. Even, if the supply air is brought trough one hollow at outdoor temperature the indoor maximum temperature can be dropped 2.2°C. If the air flow is doubled and conducted trough one hollow, the drop in indoor temperature is 6°C in south faced room. By increasing air flow and number of the cores as air channels, indoor temperature can be dropped even 8°C. In north faced room, the indoor temperature can drop from 29.8°C to 24.1°C by using hollow-core slab and increasing air flow. All in all, the excess cooling power is needed at least south faced rooms to achieve indoor temperature 24°C. However, the required cooling power is smaller than in case the hollow-core is not used.

The laboratory tests showed that during the summer night hollow-core slab preheats the incoming cool supply air from +9 °C to +14 °C. Hollow-core slab stores 40 - 70 % of the total cooling energy of supply air. Average storing capacity is 25 W/m² (supply air flow is 40 dm³/s) and 14 W/m² (20 dm³/s) (slab area 12 m²). Less supply air preheating is needed in air handling unit. Most of the time the slab preheats the supply air enough. During the hot summer day hollow-core slab cools down the incoming hot day time supply air from +29 °C to +23 °C. Hollow-core slab stores 60 - 95 % of the excess heat load of hot supply air. Average storing capacity is 20 W/m² (40 dm³/s) and 9 W/m² (20 dm³/s).

Minimum surface temperature of the hollow-core slab in cooling case was +16 ... +19 °C. Lowest temperatures were measured near the supply air inlet of the hollow-core and straight above the hollow-core used as air duct. Surface temperatures do not create any condensation problems or uncomfortable thermal conditions. Even more uniform temperature distribution was measured when extra surface slab was used.

For the full utilisation of the thermal mass it is recommended to use at least two hollow-cores per slab as supply air ducts.

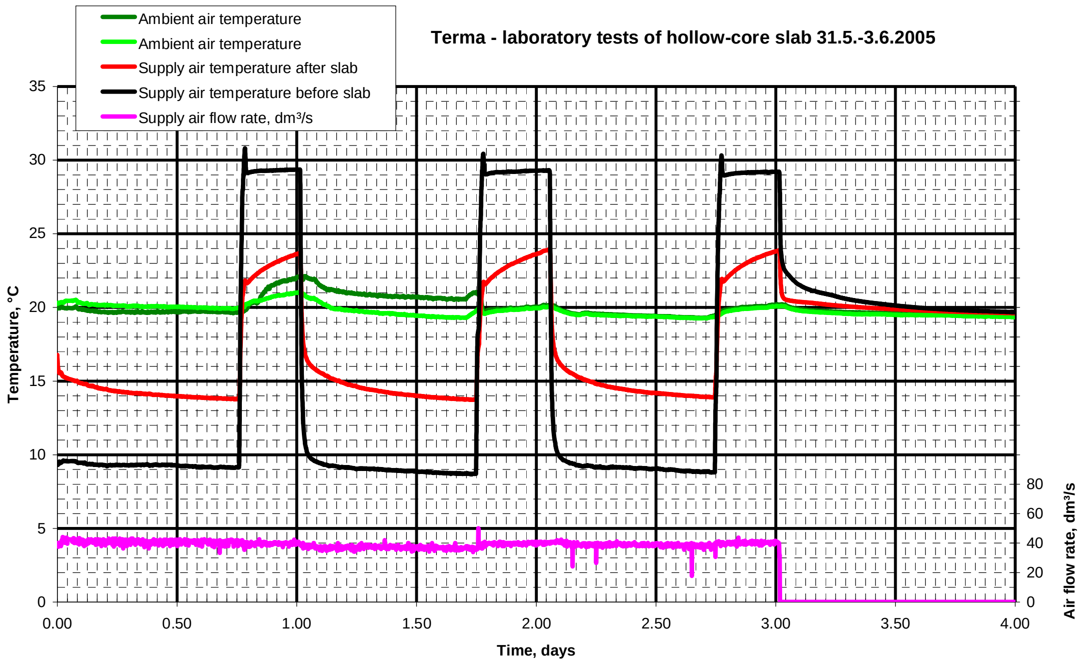


Figure 7. The air temperatures of the hollow-core slab, air flow rate 40 dm³/s, one core as air duct.

After multiphysics simulations and laboratory tests the main TERMA concepts were fixed /11/. TERMA concept utilises thermal mass by air circulation. Both supply and exhaust air distribution and additional night time forced air circulation can be integrated to utilise hollow-core concrete slab (Figure 8). The basic strategy for thermal mass utilisation is:

- *Cooling season*: the slab is cooled down during unoccupied time by night ventilation or forced air circulation to decrease the day time cooling need in the room.
- *Heating Season*: the ventilation air need to be heated less mechanically when the supply air is reheated in the slab by day time heat gains.

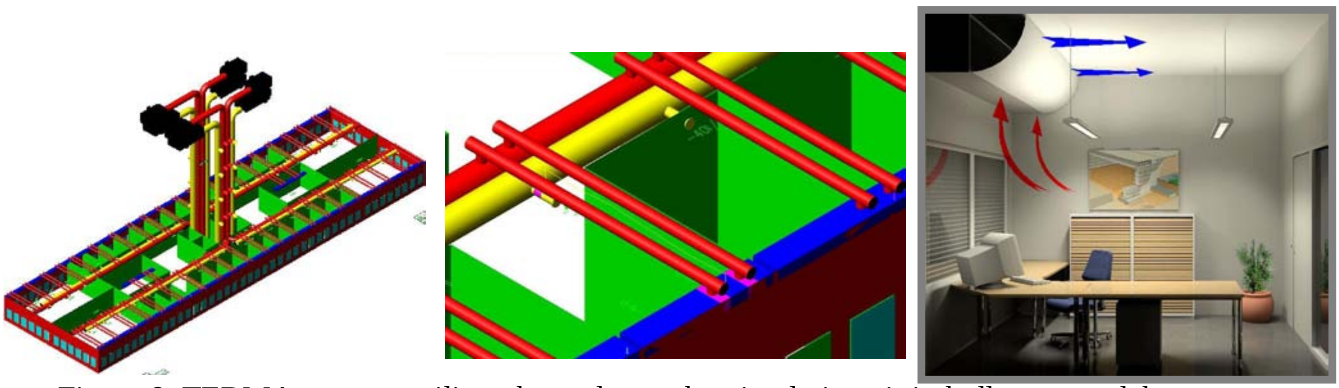


Figure 8. TERMA concept utilises thermal mass by circulating air in hollow-core slabs.

The concepts are divided in four main concepts (TERMA Alfa, TERMA Beta, TERMA Gamma and TERMA Future) which are presented in Figure 9. The characteristics of the different concepts are also presented as well as potential level of energy savings.

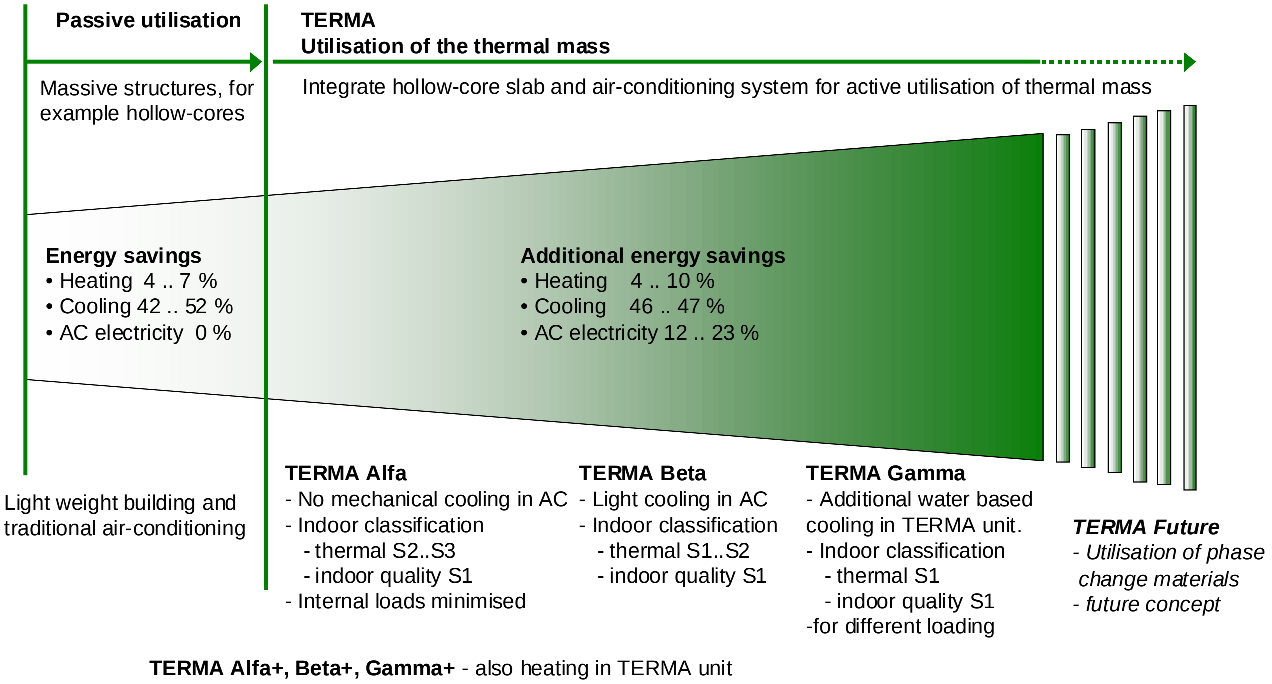


Figure 9. TERMA concepts to fulfil different requirements of building use and indoor comfort.

CFD simulations were used to confirm good thermal comfort for critical parts of occupied zone by using different TERMA concepts. Figure 10 shows the indoor conditions in TERMA Gamma system /10/.

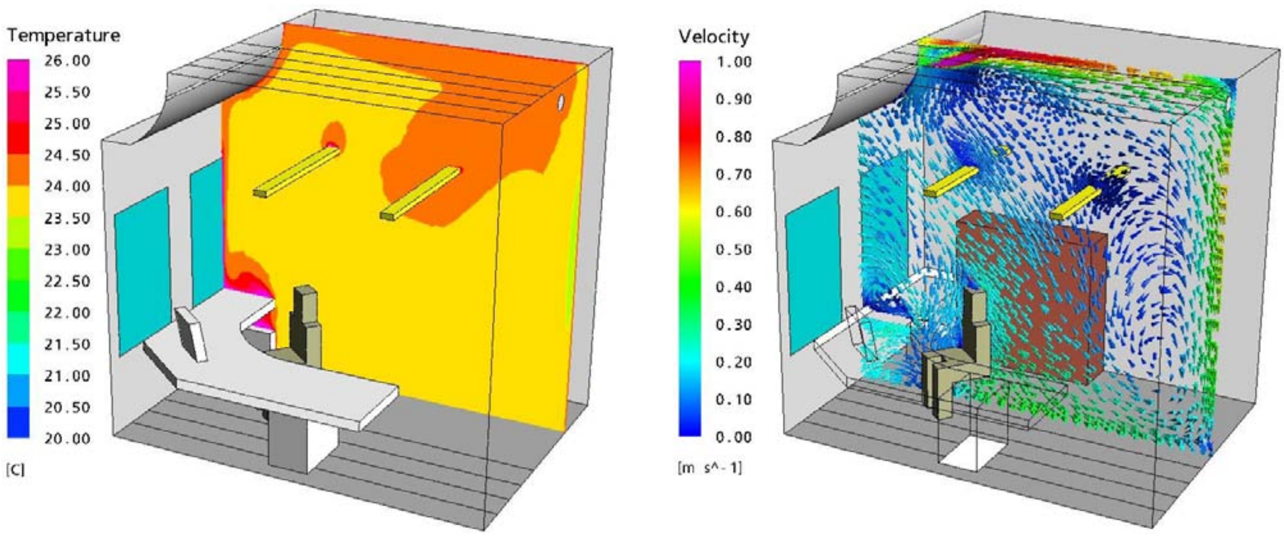
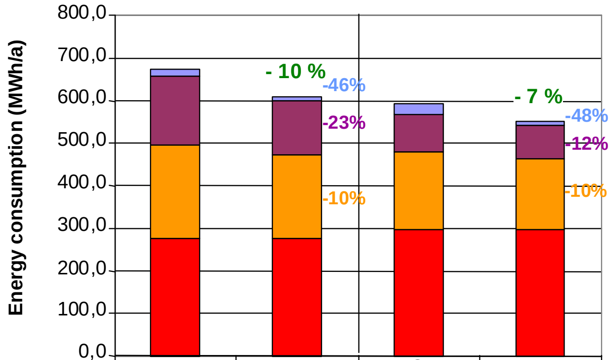


Figure 10. Indoor conditions in TERMA Gamma concept.

TERMA concepts save cooling energy almost 50% (46-47%) compared to traditional variable air volume (VAV) system or cooled beam (CB) system, Figure 11. The saving potential in fan electricity is 12-23% which is indirectly related on cooling, because of smaller air flows in TERMA concepts than in other systems. The heating of the supply air is reduced appr. 10%

and total heating energy of the building appr. 4% compared to traditional AC systems, VAV and CB system /8/.



	VAV	TERMA β	CB	TERMA γ
Cooling electricity	16,5	8,9	24,0	12,6
Fan electricity	164,4	127,4	89,2	78,8
Air ventilation heating	218,6	197,0	181,7	163,8
Space heating	276,3	276,3	297,7	297,7

Figure 11. The energy consumption of the office building.

DISCUSSION

The basis of the concept development in TERMA was in advanced modelling and simulation analysis and laboratory measurements. The simulation models were validated against laboratory measurements. Therefore, the reliability of the hollow-core slab multiphysics simulation was improved considerably. The modelling and simulation gave a good background for development of the new TERMA concepts. The results of the project were good. Four different concepts which integrate thermal mass of hollow-core slabs and air-conditioning system were developed and almost 50% of cooling and 4..10% of heating energy savings potential were recorded.

ACKNOWLEDGEMENT

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REFERENCES

1. Sormunen, P, Laine, T, Rakenteiden massiivisuuden ja tiiveyden vaikutus energiankulutukseen. Olof Granlund Oy (in finnish).
2. Hietamäki, T, Kuoppala, J-M, Kalema, T, Taivallahti, T. 2003. Rakennusten massivisuus. Keskeiset tutkimukset ja tulokset . Tampereen Teknillinen Yliopisto. Energia- ja prosessitekniikan laboratorio. (in finnish)
3 Laine, J, Saari, M. 2004. Tilannekatsaus termisen massan hyödyntämismahdollisuuksista VTT Technical Research Centre of Finland, Espoo. (Research Report No VTT-RTE3628/04) (in finnish, abstract in english)

4. Sormunen, P.2004. Tilannekatsaus faasimuutosmateriaaleihin rakentamisessa. Olof Granlund Oy. (in finnish)
5. Laine, T. Sormunen, P. 2004.Yhteenveto potentiaalisista järjestelmäkonsepteista. Olof Granlund Oy. (in finnish)
6. Sormunen, P. Laine, T. The efficiency of using the hollowcore slab as a thermal storage. Olof Granlund Oy.
7. Jokela, M, Keinänen, A, Lahtela, H, Lassila, K. 1997. Integrated building simulation tool - RIUSKA, Olof Granlund Oy. Helsinki. 6 pages.
8. Laine, T, Mairinoja, P. Myllymäki, O. Herronen, N. 2006. Energiankulutus ja elinkaarikustannukset. Olof Granlund Oy. (in finnish)
9. Laine, J, Saari, M. 2006. Results of the laboratory tests of hollow-core slab with and without topping. TERMA - Utilisation of thermal mass of structures by integration of the building frame and HVAC. Requested by: Parma Oy. VTT Technical Research Centre of Finland, Espoo. (Research Report No VTT-R-10292-06)
10. Laine,T, Lestinen, S.2006. Comfort analysis by CFD-simulations. Olof Granlund Oy.
11. Laine, T. Laine, J, Saari, M. 2006. TERMA järjestelmäopas. Olof Granlund Oy. (in finnish)