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Experimental Investigation of Thermal conductivity of natural Palm Tree Trunk's Tissues and Fibers

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Abstract— It was repeatedly reported that the clay bricks industry faces both weak mechanical strength and poor quality which normally causes marketing problems where it is expected to serve the increasing demand of housing generally in the third world countries and particularly in Jordan especially after the political crises in the neighboring countries Iraq and Syria. It is therefore anticipated that improvement of the mechanical strength and thermal insulation characteristics utilizing the available waste material in addition to the quality of the produced clay brick industry is worth investigating. Thermal conductivity is an important parameter in material selection for design, manufacturing and application of engineering and industrial components either when used as insulator or conductor.

Index Terms— Experimental investigation, Thermal conductivity, Resistivity, Effect, temperature, time, Palm tree trunk, Tissues, Fibers, Thermal insulation, Clay bricks, Energy saving, Kingdom Saudi Arabia, KSA.

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1 Introduction and Literature Review

The available literature reveals that brickmaking industry is probably the second earliest industry of mankind after agriculture. The archaeological excavations have indicated that oldest sun-dried bricks have been found beneath the foundations of the old city of Jericho in the Jordan River valley, a little north of the Dead Sea, about 9000 to 10000 years ago when there were no molds used at that time. These excavations indicate that clay has existed in Jordan and have been in use since the old ages. Ever since, the art of brickmaking had advanced to the process of firing. In 1955 MILLS [1] published a book about clay bricks from the stage of manufacture to the stage of use. It seems that this book is the first in the field. Later, the mineralogical aspects of clay using differential thermal analysis is given in reference [2]. Simple manuals for brickmaking to be used with villagers to enable them to make good and cheap clay bricks are given in references [3, 4]. The bricklaying is also used as a craft and reported in references [5-8]. However, the introduction of the heavy clay technology was not forwarded until 1969 in reference [9]. A detailed review of brickwork which is based on engineering design and scientific research which provided the recent developments in brickwork technology is given in reference [10]. This formed the basis for the manufacturing of prefabricated and prestressed bricks. A new trend in the research of brickwork where a good manual which describes a method of stabilizing sun-dried adobe bricks which are water proof, high strength, durable, and little maintenance and keep up are required were reported in 1972, [11,12]. After 1972, voluminus research papers appeared in the literature on clay bricks all over the world both in indusrial and developing countries in attempts to improve its mechanical strength, durability and surface quality, [13-20].

Buildings in general, of which brickmaking industry forms main part of it, are among the largest sectors in energy consumption particularly the HVAC systems e.g. in the United States the building sector consumes 40% of produced energy and in KSA this sector consumes about 80% where the HVAC consumes 70% of it, [21]. Recently, a global trend started in energy saving by the effective use of energy in buildings (residential, public or governmental), in order to reduce fossil fuel usage in heating and cooling and reduce emissions resulting from the heating systems. In a study on one of the buildings in KSA it was found that 66% of the electricity consumed in summer, goes to cool the buildings [21]. Therefore, it is anticipated that investigating the thermal insulation by utilizing local available materials is of prime importance as it plays a major role in reducing the consumption of electrical energy used for air conditioning and heating by reducing the leakage of heat through walls and ceilings which in turn leads to a substantial saving. This formed the main objective of this research work. The use of thermal insulation is regarded as one of the most effective means of energy conservation in buildings. The thermal resistance offered by an insulation layer increases with increasing layer thickness and decreasing thermal conductivity. Under dynamic conditions (as the case is in most practical applications), insulation materials also play an important role in affecting other thermal characteristics such as the decrement factor, time lag and peak transmission loads. Many types of insulation materials are available which differ with regard to thermal properties and many other material properties as well as cost. Different insulating practices are available depending upon the overall structures of walls and roofs.

The R-values used to design building walls and roofs structures depends strongly on the thermal conductivity of insulation materials. Besides, thermal analysis procedures of building

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components or the building as a whole, which provide alternatives to heat transmission measurements in laboratory and prototype situations, need thermal property values as input to their calculation.

The main objectives of this work are: First to find new natural materials with low thermal conductivity obtained from local sources that can be used as insulating material, in many applications where heat loss is unwanted especially in buildings and second to utilize the palm tree tissues and fibers for the Determination of thermal obtained from KSA local resources. It is expected to find new information based on scientific research about palm trees challenges in desert areas.

The palm tree succeeded to live in this very hot climate environment because of its roots that can reach water sources in deep land layers, but it is not the only reason; from the point view of thermal engineering it can be explained that this tree is capable of protecting its own inside material and liquids because of the unique bark palm, tissues and fibers which wrapped around the trunk. So studying the thermal properties of the layers of palm parts will lead to new knowledge about this great tree.

The palm tree was chosen in the investigation for two reasons: The first is due to its availability in large quantities in most Arab countries and the second: it succeeds to live and grow in severe hot conditions because of its roots can reach water sources at very low depths from the ground and it is capable of protecting its own inside material and liquids from dryness due to the unique bark palm, tissues and fibers which are wrapped around the trunk. The adopted research approach is based on experimental determination of related thermal and mechanical properties of materials extracted from palm treetrunk. .Extreme care will be observed on specimens' preparation to obtain a good quality material from different trees according to age and location. Specimen(s) testing will be conducted using the thermal conductivity measuring method, which is a heat flow meter method that complies with International Standards for steady-state measurement, ISO8301 and with an acceptable accuracy level;

It is expected that investigating the thermal properties of the layers of palm parts will lead to new knowledge about this great tree. Large quantities of date palm rachis and leaves wastes may be found every year once the palms' fruit are harvested. These important amounts of biomass wastes are of potential interest as they can be considered as natural fiber sources [22] that may be used in diverse industrial applications. Several studies proved that date palm fibers have the potential to be an effective filler in both thermoplastics and thermosetting materials to be used in different industrial applications. [23- 25]

It is estimated that a sole date palm tree can produce annually more than 20 kg of dry leaves and fibers [26]. However, to be able to estimate the annual production of a country in terms of fibers, the total number of date palm trees should be known. Saudi's grove feature more than 20 million trees and more than 320 varieties of the fruit. [26,27] In 2004, it is reported that the estimated number of date palm trees in Saudi Arabia was 18 million and its annual production of dates estimated at 700,000 tons [28]. In 2007, the date palm plantations in the Kingdom occupied 150,744 ha where 23 million trees produced 970,488 tons of date's annually [29].

Date palms begin to bear fruit at 3 to 5 years, and are fully mature at 12 years. A tree may produce between 5 and 10 bunches, each weighing between 6 and 8 kg. A fully productive palm can support 8-10 bunches weighting as much as 60-100kg.

The adopted research approach is based on experimental determination of related thermal conductivities of specimens taken from different layers and different ages of palm trees trunks to investigate the possibility of utilizing them as thermal insulators in the clay bricks industry in the Kingdom of Saudi Arabia, KSA, and other Arab countries.

TABLE 1
TOP TEN COUNTRIES IN PRODUCING DATES IN THE WORLD

Ranking	Country	2012 (metric tons)
1.	Egypt	1,470,000
2.	Iran	1,066,000
3.	Saudi Arabia	1,050,000
4.	Algeria	789,000
5.	Iraq	650,000
6.	Pakistan	600,000
7.	Oman	270,000
8.	United Arab Emirates	250,000
9.	Tunisia	190,000
10.	Libya	170,000

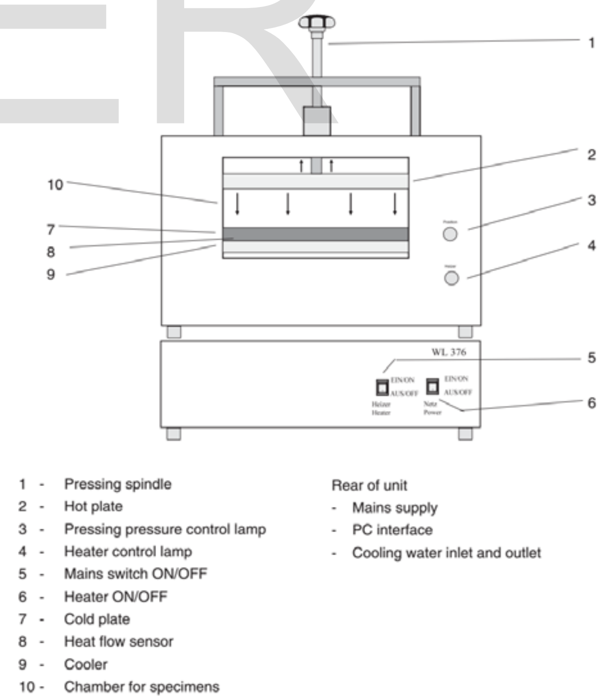

Fig. 1. A schematic drawing of the thermal conductivity apparatus

Extreme care was taken into consideration in preparation of the specimens to obtain a good quality material from different trees according to age and location. Testing of the specimens was conducted using the standard thermal conductivity measuring method shown in the schematic drawing of figure 2. This method is a heat flow meter method which complies with International Standards for steady-state measurement, ISO830 with an acceptable accuracy level.

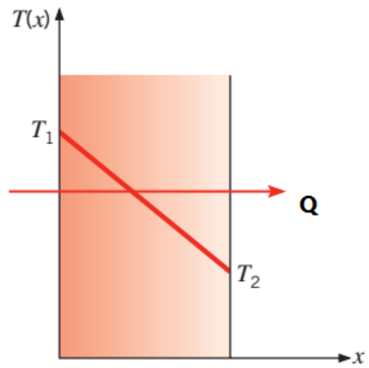

Fig. 2. Heat flow conductivity through flat wall

2 *Theoretical* Considerations

The thermal conductivity of the different materials was determined from the proportionality between heat flow and the applied temperature difference (Fourier Law) as follows:
Consider a quantity of heat Q is flowing through a cross-sectional area of a solid body, where its cross sectional area, A, is significantly greater than its peripheral and the elapsed time to reach a steady state condition is t, then according to Fourier's Law, the heat flow Q due to the thermal conduction through a flat wall as illustrated in Figure 2 is described by the equation of the steady state condition as follows:
The heat flow low, Q, through a flat wall for period of time t, is determined *from* equation (1) which at a constant cross sectional area, A and distance dx it becomes:

$$Q = A\frac{\lambda}{d}(T_1 - T_2) \qquad (1)$$

where
Q: Heat flow in (W).,
λ: Thermal conductivity (W/m. K).
A: Area (m2). T = Temperature (˚C).
x: The wall thickness

Tabulated values of thermal properties of insulation materials are available in the open literature. Manufacturers' claimed values of thermal properties of locally produced insulation materials could also be found in brochures and leaflets. Such data values are very useful but must be used with extreme care. Accuracy of these property values is sometimes questionable since completer are many Saudi manufacturers that produce different types of thermal insulation materials with different densities for use in buildings and other applications. These insulation materials are: molded polystyrene, extruded polystyrene, injected polystyrene, polyurethane board, glass fiber, rock wool, and loose fill perlite.
Table 2 gives the thermal properties of some insulation materials measured at room temperature together. Also the claimed thermal properties values. as given by the manufacturers are included for comparison purposes. It should be noted that the values claimed by manufacturers should be carefully checked before being used.

3 Results and Discussion

In this study, tests were performed on natural materials

TABLE 2
Thermal properties of insulation materials measured at room temperature; showing comparison with manufacturers' claimed conductivity values, [35].

Material	Density (kg/m^3)	Thermal conductivity (W/m K)	
		Measured	Manufacturer
Molded polystyrene	19 ± 1	0.036 ± 0.0002	0.034
	23 ± 1	0.034 ± 0.0009	0.033
	38 ± 1	0.033 ± 0.0002	0.032
Extruded polystyrene	28 ± 1	0.032 ± 0.0003	0.032
	34 ± 2	0.031 ± 0.0003	0.032
Injected polystyrene	20 ± 2	0.034 ± 0.0004	0.034
	34 ± 1	0.033 ± 0.0008	0.032
Polyurethane board	28 ± 1	0.024 ± 0.0005	0.023
	33 ± 2	0.022 ± 0.0003	0.023
Lightweight concrete	551 ± 3	0.155 ± 0.0031	0.120
Perlite (loose fill)	94 ± 4	0.054 ± 0.0017	0.04–0.06[b]
Glass fiber (axial)	30 ± 1	0.042 ± 0.0006	0.035
	95 ± 1	0.038 ± 0.0008	0.034
Rock wool (axial)	50 ± 1	0.042 ± 0.0002	0.042
	120 ± 1	0.040 ± 0.0010	0.037
Glass fiber (radial)	30 ± 1	0.034 ± 0.0012	–
	95 ± 1	0.046 ± 0.0023	–
Rock wool (radial)	50 ± 1	0.042 ± 0.0016	–
	120 ± 1	0.049 ± 0.0012	–

taken from palm tree. Those materials are listed in Tables 3 and 4. The tested materials are classified as follows: i). Palm tree materials with unknown thermal properties of fibers 1, 2, 3 and 4 which belong to trunk wood, palm's fine seeds, coarse seeds and palm's leaves respectively. ii). Insulation materials with known thermal properties and considered as good insulators e.g. Rock wool, polystyrene and cork. Those materials are actually used in buildings and others applications. iii). Materials used in building walls and floors such as gypsum, cement, local marble, Italian marble and concrete. The used parameter is the thermal conductivity device for building materials, which is used for low thermal conductivities. The thermal conductivity of each specimen was measured five times at different temperatures at increasing increments of 10°C; namely: 40, 50, 60, 70 and 80 °C. The time required to reach the steady state condition for each specimen was about five hours. Figures 3 and 4 show the relationship between the time required to reach the steady state condition, which is the needed time for measuring the thermal conductivity (λ) and thermal resistance (R).

The measured values of thermal conductivity (λ) shown in Figures 3, 4 and Table 3; for the tested materials ranged between 0.035 W/m.K to 0.0567 W/ m.K over the mean temperature range from 40°C to 80°C. These λ values are within the range 0.02 W/m.K to 0.06 W/m.K which is normally used for thermal building insulation, [32]. Hence it can be concluded that the thermal conductivity of fibers 1-4 together with the other tested palms specimens in this research work have a good potential in utilizing them as thermal insulators in buildings. The thermal conductivity of fiber (4) represents the highest value among the tested materials being 0.069 W/m.K. Also this specimen has the highest density because it is taken from the top of the palms truck which means that it is new fiber and not yet dried as the old fibers. It is well known that the thermal conductivity (λ) increases with increasing density. Furthermore, it can also be seen from figures 3,4 and Tables 3,4 that specimens made from fine and coarse seeds have lower thermal conductivities than specimens made from other samples from materials of higher densities.

THE INSULATION MATERIALS ARE USUALLY SUBJECTED TO DIFFERENT TEMPERATURES DURING THEIR

TABLE 3
MEASURED THERMAL PROPERTIES AND DENSITIES OF SOME SELECTED MATERIALS

No.	Sample	Density (kg/m^3)	Thermal Conductivity λ (W/m.K)
1	Fiber 1	277.8	0.037-0.038
2	Fiber 2	297.8	0.0471-0.0498
3	Fiber 3	353.34	0.046-0.0523
4	Fiber 4	383.65	0.0633-0.0690
5	Seeds Fine	825.56	0.0524-0.0555
6	Seeds Coarse	954.45	0.0502- 0.0563
7	Leaves	353	0.0467-0.0506
8	Wood trunk	530	0.047 -0.0567
9	Cork	167	0.0369-0.0387
10	Rockwool	164.16	0.0405-0.05
11	Cement	1419.2	0.1666-0.1918
12	Gypsum	854.2	0.1646-0.1773
13	Marble local	2650	0.9996-1.1530
14	Polystyrene	26.3	0.0368-0.0394
15	Marble Italian	2650	1.1025-1.1237

TABLE 4
SELECTED MATERIALS AND THEIR MEASURED THERMAL CONDUCTIVITIES AT DIFFERENT TEMPERATURES

	Thermal Conductivity (W/m. K)				
	Temperature (°C)				
Materials	40	50	60	70	80
Fiber 1	0.038	0.037	0.037	0.0377	0.0375
Fiber 2	0.0523	0.0471	0.049	0.0498	0.0485
Fiber 3	0.0475	0.0475	0.046	0.047	0.0479
Fiber 4	0.0690	0.0664	0.0654	0.0633	0.0652
Palm leaves	0.047	0.0488	0.0484	0.0467	0.0506
Trunk Wood	0.0567	0.0509	0.0472	0.0467	0.0452
Fine seeds	0.0537	0.0543	0.0555	0.0524	0.0541
coarse seeds	0.0545	0.0546	0.0515	0.0502	0.0563
Rockwool	0.05	0.0443	0.0398	0.0384	0.0405
Cork	0.0369	0.0380	0.0383	0.0369	0.0387
Cement	0.1727	0.1666	0.1731	0.1893	0.1918
Gypsum	0.1646	0.1756	0.1773	0.1751	0.1751
local Marble	1.1530	1.0831	1.1321	0.9996	1.0271
Polystyrène	0.0377	0.0386	0.0394	0.0368	0.0363
Italien Marble	1.1176	1.1025	1.1237	1.1231	1.1230

SERVICE LIVES. IN THIS RESEARCH WORK THE THERMAL CONDUCTIVITY OF EACH SPACEMEN WAS MEASURED OVER THE TEMPERATURE RANGE FROM 40°C TO 80°C AS SHOWN IN FIGURE 3. IT CAN BE OBSERVED FROM THIS FIGURE THAT FOR MOST OF THE SAMPLES THEIR THERMAL CONDUCTIVITIES (λ) HAVE SMALL CHANGES WITH TEMPERATURE VARIATION. HOWEVER, IT WAS FOUND THAT BOTH THERMAL CONDUCTIVITY AND THERMAL RESISTANCE SHOWED APPRECIABLE VARIATION WITH TIME AS ILLUSTRATED IN FIGS. 5 AND 6. FIGURE 7 INDICATES THAT THE HEAT FLOW DENSITY AND HOT PLATE TEMPERATURE, T2, INCREASE WITH INCREASE OF TIME WHEREAS THE COLD PLATE TEMPERATURE, T1, AND THE COOLING WATER TEMPERATURE, T3, DID NOT SHOW ANY PRACTICAL VARIATION WITH TIME AND ALMOST REMAINED CONSTANT.

The results also showed that the palm tree materials are close or lower than the thermal conductivities of other materials used as thermal insulator in buildings as agricultural by-products, oil palm, coconut sugarcane fiber, sunflower stalk, textile waste, stubble fibers waste, wood wool, straw and cane which were investigated and reported in [31-33]. The thermal conductivity (λ) for those materials ranged from 0.04160 W/m. K to 0.06 W/m. K which is in good agreement with our obtained results of the palm tree materials.

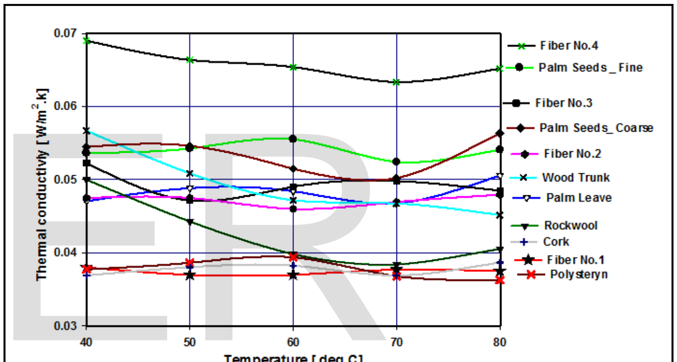

Figure .3:Thermal Conductivity vs Temperature

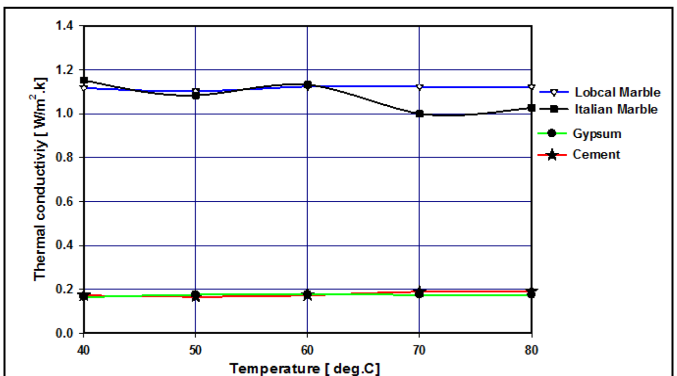

Figure .4: Thermal Conductivity vs Temperature

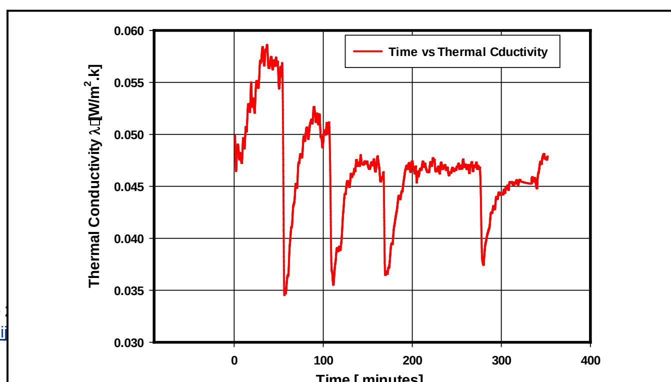

Figure. 5: Time vs Thermal Conductivity

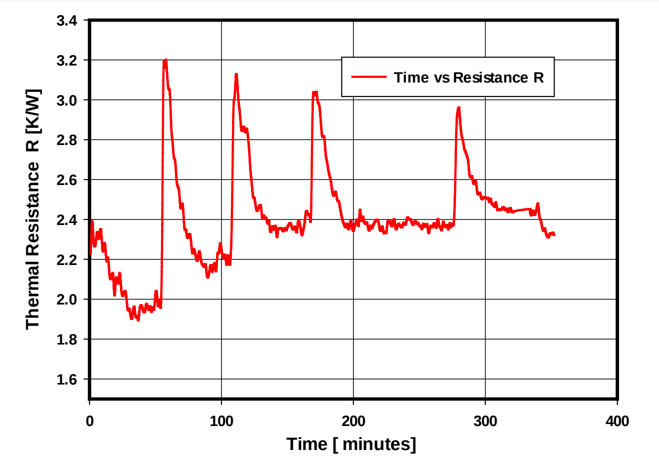

Figure 6:Time vsThermal Resistance

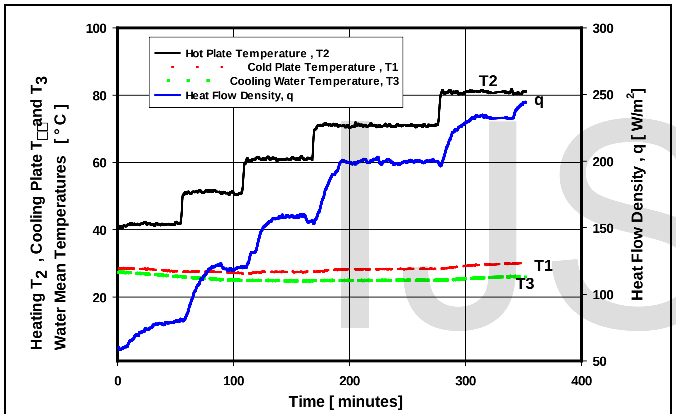

Figure. 7 : Time vs heat flow density , plates and cooling water temperatures

4 Conclusions

The main objective of this research wok is to investigate the possibility of utilization of the local available material namely the palm tree parts e.g. The truck wood, fibers, seeds as thermal insulators in the clay brick industry. The main parameter for this purpose is the thermal conductivity. This parameter was determined at diffent temperatures and time together with other important parats e.g. density, thermal resistivity. The following points are concluded.

i). The thermal conductivity was successfully determined for all the above mentioned parts using the International Standards for steady-state measurement, ISO8301.the obtained values of their thermal coductivity ranged from 0.037 W/m.K for fiber No.1 and 0.069 W/m.K for fiber 4. These values were compared with the values repoted by ASHRE for other insulating materials and close agreement was found between the results.

ii), For most of the tested material within the experimental limitations, the thermal conductivity did not show any appreciable variation with tempeerature changes.

.iii). Both the heat flow density and hot plate temperature showed increase with increase of time, whereas the cold plate temperature and the cooling water temperature did not show any practical variation with time and remained almost constant.

iv). Utilization of the local available materials as insulators in buildings for walls roofs and windows is of prime importance as it plays a major role in reducing the consumption of electrical energy used for air conditioning and heating by reducing the leakage of heat through walls and ceilings which in turn leads to substantial saving.

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